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A COMPREHENSIVE GUIDE TO C^3
SYSTEM DEVELOPMENT

by

Shin, In Sub

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Thesis co-advisor: Carl R. Jones
Thesis co-advisor: Dan C. Boger

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A Comprehensive Guide to C^3 System Development

by

Shin, In Sub
Captain, Republic of Korea Army
B.S., Republic of Korea Military Academy, 1985

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Author: ______________________
Shin, In Sub

Approved by: ______________________
Carl R. Jones, Thesis Co–Advisor

____
Dan C. Boger, Thesis Co–Advisor

____
David R. Whipple, Chairman,
Department of Administrative Sciences

ABSTRACT

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I. INTRODUCTION

A. THE HISTORY OF COMMAND

The problem of commanding and controlling armed forces, and instituting effective communications with and within them, is as old as war itself. A Stone Age chieftain had to devise the optimal organization and find the methods and technical means to command the forces at his disposal. [Ref. 1:p. 1]

The history of command in war consists essentially of an endless quest for certainty—certainty about the state and intentions of the enemy's forces; certainty about the manifold factors that together constitute the environment in which the war is fought, from the weather and the terrain to radioactivity and the presence of chemical warfare agents; and, last but definitely not least, certainty about the state, intentions, and activities of one's own forces. [Ref. 1:p. 264]

Certainty itself is best understood as the product of two factors, the amount of information available for decision making and the nature of the task to be performed. An invisible hand, much like that which, according to Adam Smith, regulates the balance between supply and demand, determines the relationships between the two. Everything else being equal, a larger and more complex task will demand more information to carry it out. Conversely when information is insufficient (or when it is not available on time, or when it is superabundant, or when it is wrong, all of which can be expressed in quantitative terms), a fall in the level of performance will automatically ensue. Thus, the history of command can be understood in terms of a race between the demand for information and the ability of command systems to meet it. [Ref. 1:p. 265]

But, the nature of the task is not the only determinant of the amount of information required for its performance; equally important is the structure of the organization itself. In other words, uncertainty is not dependent solely on the nature of the task to be performed; it may equally well be a function of a change in the organization itself. [Ref. 1:pp. 268–269]

B. BATTLE MANAGEMENT AND C^3 SYSTEM

Battle management is the process of managing a battle with the intent of destroying an enemy's weapon system [Ref. 2:p. 1]. A battlefield management system needs an electronic information gathering, processing, and distribution system, handling real–time battlefield information in a responsive manner. It is designed to facilitate timely and well–founded battlefield decisions at the fighter level [Ref. 3:p. 28]. That function is performed by a battle manager through a system called Command, Control, and Communications (C^3) [Ref. 2:p. 1]. The decisions of battle managers will be based on the best information available from the C^3 system.

However, confronted with a task, and having less information available than is needed to perform that task (another form of its difference is uncertainty), an organization may react in either of two ways. One is to increase its information processing capacity, the other is to design the organization, and indeed the task itself, in such a way as to enable it to operate on the basis of less information [Ref. 1:p. 269]. Thus, the components of the C^3 system must include organizational design and technical means for information processing.

Given the uncertainty, each battle manager incurs a risk in managing the battlefield or his forces to the degree of his own uncertainty in time. It is obvious

that the decision by a battle manager with the relatively less certainty has the higher probability to cause a negative response to the battlefield environment than the decision with the relatively greater certainty does. Also, greater certainty at the top is only bought at the expense of less certainty at the bottom. In other words, if the top battle manger has greater certainty, he will control his lower level command with superior strength and have his forces in reserve monitoring until he confirms that the situation is in favor of his forces. The lower level battle manger, however, will operate his forces based on the ad hoc directives from the higher level command with less certainty about the overall situation. In this case, the probability of a negative response in the higher level command is low, but once this happens, the lower level battle manager has a high challenge to solve this problem because his operation is highly dependent on the higher level battle manager. It requires a strong control mechanism. So the uncertainty management style will determine the types of control of the organization: centralization and decentralization [Ref. 1:p. 274].

In the centralization type of control, information merges to the top battle manager. So the top manager has greater certainty for decision making, but the bottom manager has to accept the expense of less certainty for situation assessment until he receives information that is transformed by the top manager. But, if he has some challenge within his responsibility area, he has the small span of control because of the lack of his own situation assessment capability. In the decentralization type of control, on the other hand, the bottom manager in the battle execution level has his own information processing capability and no time delay of information circulation between top and bottom managers. But, he has to accept the larger deviation of the uncertainty. The certainty on his part is

generated by the narrow sources of information. If an event occurs within his interested area, he will evaluate the situation in his point of view, then the situation assessment will have a larger deviation statistically due to the small volume of information.

Among the considerations that permeate the command and control process and supporting C^3 systems, those of uncertainty and time are key criteria for selection of C^3 systems because the achievement of a timely reduction of uncertainty facilitates intelligent decision making. As it will be seen, much of command and control effort is expended to reduce both time and uncertainty, so that a key characteristic of any military organization is the way that time for planning and for uncertainty reduction are allocated to the different echelons of command. [Ref. 4:p. 11]

C. THE NATURE OF WAR AND MODERN TECHNOLOGY

As a result, the best command system is to reduce the time–uncertainty product. But, it is important to recognize that the nature of warfare puts some practical limits on our ability to create a "perfect" C^3 system that would eliminate uncertainty because combat is not a deterministic process [Ref. 4:p. 11]. As Clausewitz also points out, war brings to the fore some of the most powerful emotions known to man, including fear, anger, vindictiveness, and hatred. Consequently, even disregarding the manifold ways in which the human mind can distort information in the very act of processing it, the quest for certainty cannot be expected to proceed rationally all or even most of the time. And war consists of two independent wills confronting each other [Ref. 1:p. 266]. To the extent that outcomes are influenced by decisions, they are influenced by decisions—some

rational, some emotional – made by commanders at several echelons on both sides.

Even though there is no perfect C^3 system due to the nature of war, reduction in uncertainty can be achieved by increasing the available knowledge through the conversion of information into knowledge. On the other hand, reduction of the needed knowledge by an individual commander can be achieved through organization design–for example, the introduction of doctrine that implements distributed decision making or the use of decision aids. [Ref. 5:p. 8]

Fortunately the modern technology of sensing system, communications system and data processing system can improve the system performance in terms of its timeliness and information fusion. Thus based on the timeliness and accuracy of outcomes from a system, the optimal C^3 system rather than the perfect C^3 system can be developed.

D. SCOPE

The purpose of this thesis is to give guidelines to Project Managers or the beginners in C^3 research about C^3I system acquisition or development. The first stage of acquisition for any weapon system is the concept definition stage. For the C^3I system, many studies have been done conceptually and theoretically. But, there is no definitive concept of a C^3I system. Nobody can tell that this is the C^3I system clearly. Some say that it is an information system, the other says it is a battle management system. Everybody has his own definition from his perspective. So, in Chapter II, the author will review studies about C^3I systems concerning with its fundamental theory, models, and applications. Then, in Chapter III, this review will drive the definition of C^3I system and its boundary in a visible way, and a integrated framework of C^3I system will be discussed with the various perspectives

for real system development. It will be the background knowledge to understand the remaining chapters. Then, Chapter IV will present a consistent approach to develop a C^3I system using the model of the integrated framework. Then, Chapter V will show a procedure to develop a C^3I system at the unified forces level as a sample case. In Chapter VI, the C^3 system operation support environments and the system development constraints will be analyzed. Finally, the last chapter will cover the system development and research trends and some recommendations for the effective implementation of the system development.

II. THEORETICAL DESCRIPTION OF C^3I SYSTEM

A. FUNDAMENTAL THEORIES

1. Command and Control

The words C^2, C^3, and C^3I have different meanings to different people, and their indiscriminate use can create a great degree of confusion. For this reason, some distinction between the C^2 and C^3 terms will be made. It is not easy to define command and control (C^2), command, control, communications (C^3), command, control, communications, and intelligence (C^3I).

a. Concepts Definition

A good starting point is the official Department of Defense definition for command and control: (JCS PUB 1)

> Command and control: The exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through arrangement of personnel, equipment, communications, facilities, and procedures which are employed by a commander in planning, directing, coordinating and controlling forces and operations in the accomplishment of the mission.

Now what is the commander trying to get his assigned forces to do? And how is he to use the personnel, equipment, communications, facilities, and procedures placed at his disposal in order to do this? This definition does not answer those questions. They are the function of command in combat operations and the command and control process.

b. C^2 Purpose and Functions

A primary function of command is deploying and maneuvering forces or other sources of potential power to be in the best possible position to

exploit opportunities as they arise. This function can be viewed as controlling the power distribution. [Ref. 6:p. 51] And command and control is that integrated function which enables the establishment of objectives and associated selection of action alternatives for force deployment. The basic C^2 functions are information gathering, situation assessment, action selection, response planning and execution, and monitoring of the implementation of alternative courses of action.

The terms of C^2, C^3, and C^3I are, however, made by adding one or more components to the backbone component, command. Thus the function of each of C^2, C^3, and C^3I has one or more additive functionality corresponding to the extra component. In terms of C^3, an effective communications system for command and control is necessary to support the information sensing, processing and transmission capability of military commanders in these tasks. This decision support system is often called a C^3 system. A major purpose of C^3 systems is intelligence analysis. And the goal of intelligence analysis is to predict human intent and behavior on the basis of retrieved information. This includes: estimates of personnel and equipment locations; the size of these elements; and their capability, options available, and intent. It is called a C^3I system. [Ref. 7:p. 55]

c. C^2 Process

A number of observers are beginning to define C^2 as a process. Usually C^2 is visualized as fundamentally a management information system with feedback loops and other elements of cybernetics, control, and decision theory.[Ref. 8:p. 29] The C^2 process is the means by which a team of human military commanders make decisions that relate to the deployment of the resources and assets assigned to them to carry out a military mission specified by a higher authority. [Ref. 9:p. 31]

2. Problem Solving – Decision Making Theory

Orr describes problem solving and decision making in terms of a state transition model quoting Dieterly's work, "Problem solving and decision making: An integration (NASA Technical Memorandum 81191, April 1980)". According to this model, the basic decision problem condition involves a state A, a state B, and a transition from state A to state B, as shown in Figure 1. Real situations can be even more complicated than indicated since it is possible to have multiple states or transitions. Situations involving multiple states usually involve probability concepts. At the same time situations involving multiple transitions require a choice for implementation and are usually associated with decision making. [Ref. 6:p. 36]

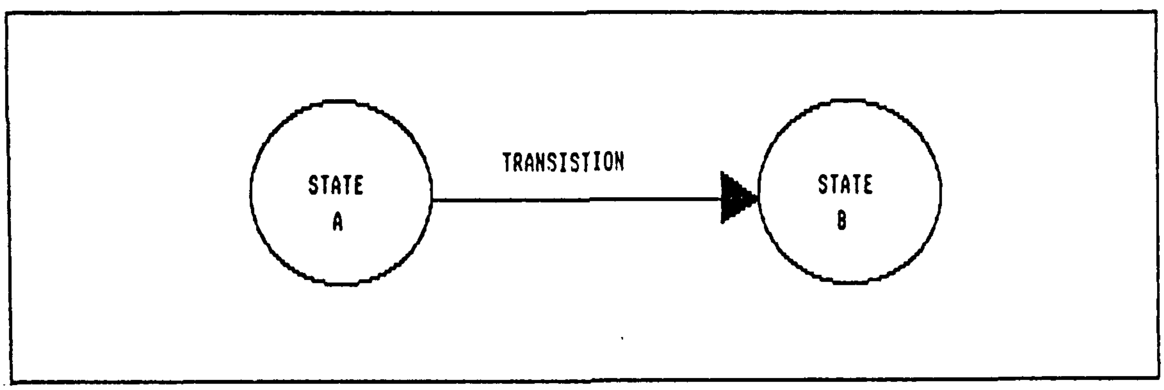


Figure 1. Basic Problem–Decision condition

A tremendous amount has been written about the decision making process. The most interesting area of research of direct use in analyzing combat operations is the utility–based decision methods. The general approach is to select a set of alternative decisions to evaluate subjectively the utility (or value to the decision maker) of outcomes expected under each decision, and to select the decision

maximizing the utility. In the event that outcomes depend upon circumstances not controlled by the decision maker, estimates of the probability of these circumstances are used to determine the expected value of the decision outcomes and the expected values are used to make the decision. [Ref. 6:p. 38]

In real life, however, and especially in combat situations, the commander's decisions may not completely determine which transition will occur. External circumstances beyond the control or knowledge of the commander may actually determine the transitions. Such conflicts are called stochastic because of the seemingly random nature of actual outcomes. Transitions involved in the stochastic process are governed by principles that can be affected by the commander's decision. Stochastic cases can be distinguished according to the amount of influence of the commander's decision. If the commander's decision completely determines which state will occur next, the commander's problem is determinant. On the other hand, if the commander's decision has no influence at all, the conflict is indeterminant from the commander's view. [Ref. 6:pp. 48–50]

In either case, the commander's decision making itself has no meaning. In fact, the decision maker avoids direct outcome predictions (which are quite sensitive to uncertainty) and instead concentrates on monitoring a few observed variables. Due to the probabilistic or stochastic nature of combat process, decisions influence the probability of outcomes rather than directly controlling outcomes [Ref 6. p. 47]. Thus the key concept required in decision making is that of the control system, especially the hierarchical control system in military command structure.

Military command style is a reference to the many somewhat arbitrary choices concerning the ways to employ available technical means within the military command structure. Mainly there are two opposed visions of the proper character

and style of military command. One is the centralized command style which is illustrated by the hierarchical control model, and the other is the decentralized command style which is illustrated by the distributed problem–solving model. [Ref. 6:p. 88]

The hierarchical control style of command attempts to turn the entire military force (or the entire nation system) into an extension of the commander. Subordinate levels respond in precise and standardized ways to his orders and provide him with the data necessary to directly control the entire military apparatus. The emphasis is upon connectivity between levels in the hierarchy, upon global information gathering or upon passing locally obtained information to higher levels, and upon centralized management of the global battle [Ref. 6:p. 87]. The primary advantage of a centralized command and control structure include: allowing the controller (decision maker) more response time to assess and/or review whatever data or information is available prior to decision making. As a result it reduces the effects of complexity and probabilism within the environment [Ref. 10:p. 324].

The distributed problem solving style, on the other hand, views the commander as controlling only in the sense of directing a cooperative problem solving effort. Commander's duties are to decompose and allocate subproblem to lower levels, to allocate resources to be used in these solutions, to determine and propagate constraints on acceptable solutions, and to monitor constantly subordinate activity. The emphasis in this style is on autonomous operation at all levels, upon networking to share the elements needed to detect and resolve possible conflicts, and upon distributed decision making process. [Ref. 6:p. 89] The advantage of this decentralized command and control style is the compensation of the disadvantage of the former control style. The major disadvantages of

centralization include a degradation of the reliability, flexibility, and survivability of the C^3 system. Another disadvantage is the increase in communications equipment requirements supporting the additional redundancy. Moreover, as information requirements increase, so do personnel requirements to process and fuse the information.

3. Military Decision Making and Control Theory

Due to the multiple states, multiple transitions, and two characteristic behaviors from both friendly and enemy sides, there is no deterministic decision making process in combat operations. Instead, the decision making process is characterized by the stochastic model which describes the multivariate micro–state process, and distributed decision making and cybernetic control theory are referred frequently because their characteristics specify the unique military organization.

Distributed decision making is a particular type of group decision making. In distributed decision making each member of the group acts individually, making decisions in an area of responsibility or expertise to advance group objectives. And each person in a group of decision makers is assumed to be using a personal library of schemata to assess situations and take actions. Each of these schemata models a different possible type of situation that may be encountered, and each is associated with a course of action. If the schemata models of the individuals are similar and if there is a common understanding of the course of action, then effective distributed decision making will be facilitated. [Ref. 11:pp. 128–129]

But it is assumed that distributed decision making is based on the doctrine of centralized planning and decentralized execution [Ref. 11:p. 127]. In other words the higher level command use centralized control style, and the lower level decentralized control style. But whatever the level is, C^3I systems are

dynamic, extremely complex, information–rich, and nondeterministic. It is also said that the purpose of C^3I system is to reduce the uncertainty as well as time. In other words it is the "*informational*" system. Production, transmission, assimilation, utilization, correlation, etc., of information–bearing elements (i.e., symbols) are their common features [Ref. 12:p.86]. This system will be specified by cybernetic control theory.

Cybernetics is the study of control and communications in complex systems. Cybernetics studies the flow of information round a system, and the way in which that information is used by the means of control [Ref. 10:p. 254]. Cybernetics gives us a language and a topology for describing complex systems, a language that explicitly identifies uncontrollable (environment) factors, the decision making functions, communications channels, and feedback. The intrinsic random nature of many of the detailed system variables requires that dynamic behavior and final state conditions be defined in probabilistic terms. The science of cybernetics gives, however, a "microscopic picture (microstates)" of the information transmission/processing/decision making process. So it is possible to analyze a behavior as a multivariate stochastic process by handling either a finite number of states or infinite number of states (no final states) [Ref. 12:p.86].

4. C^3I in Combat Operations

A lot of work has been done on defining the C^2 process. A convenient model of the command and control process can be derived by considering it to be a cybernetic system which is attempting to control the environment around it. Examples of the model are Lawson's basic C^2 process model and Boyd's O–O–D–A Loop structure.

a. Lawson's Model

In Lawson's model, the process starts with a sensing of the environment. This sensed data must be processed in some way to provide a perception of the environment. Data on the environment can be provided by external sources. This is followed by a comparison of the resulting perception of the environment with some "*desired state*" of that environment, generally established by higher authority. Based on this comparison, decisions are made and actions initiated to bring the environment into closer conformance to the "*desired state*". But what people usually think as a "*command and control process* " really has no effect on its environment. So the forces assigned to that commander must be included. That is, the commander can only really control changes in his environment by the threatened or actual delivery of ordnance on one or more targets. Figure 2.1 shows such a model, which provides for interaction between the environment and the command and control process through its assigned forces. [Ref. 13:pp. 64–69]

b. Boyd's Model

The basic O–O–D–A loop structure model suggested by Boyd's work shows observation–actions dynamics. Just as people must be able to read before they can write, one must be able to observe before they can act. As showi. Figure 2.2, Boyd's O–O–D–A loop structure consists of *OBSERVE, ORIENT, DECIDE, and ACT* functions which are identical to *SENSE, PROCESS, DECIDE, ACT* functions in Lawson's model. [Ref. 6:pp. 26–27]

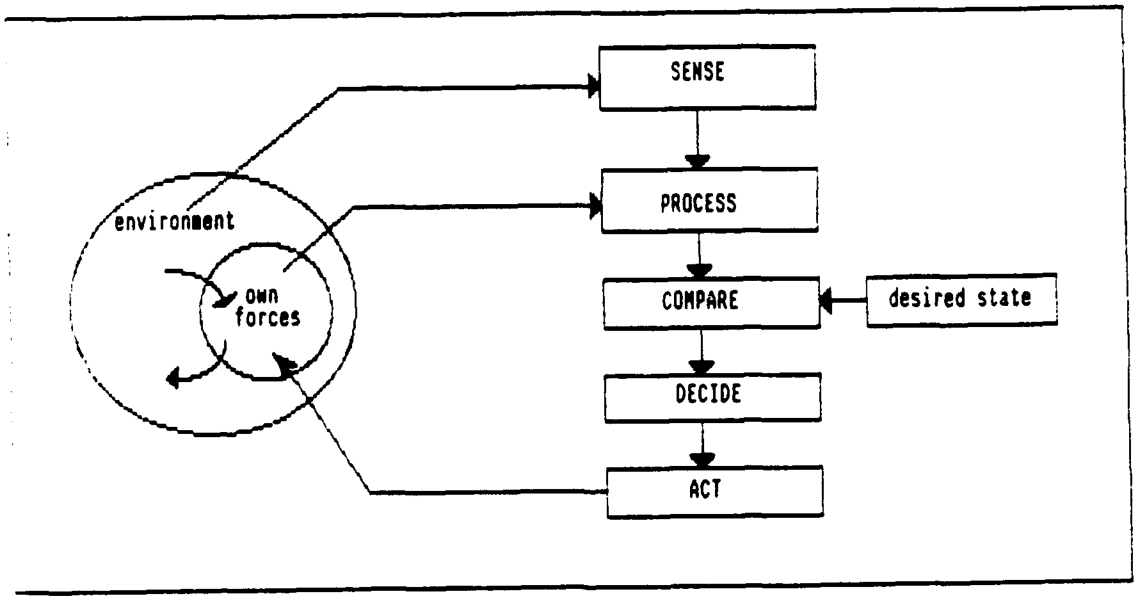


Figure 2.1 *Lawson's Thermodynamic Model*

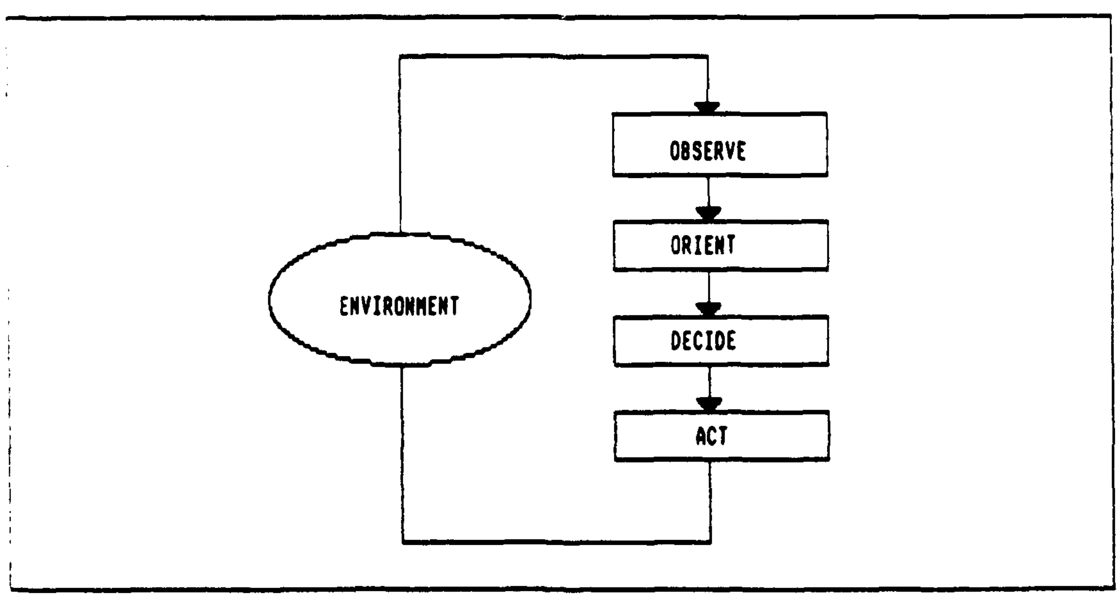


Figure 2.2 Body's O–O–D–A Loop structure

c. Implications of C^3I in Combat Operations

The common feature of those models is the simple feedback control loops. Simple feedback loops depend on essentially continuous control by the control mechanism. While this applies sometimes with the process models, control is not always continuous, especially at higher command levels. There are some time delays at various stages. Also there are two or more levels of cooperative control systems connected into an organized whole in combat operations. A single control system at the highest level controls the overall behavior of the system. This system perceives the errors between the actual and observed state and acts to eliminate them. Instead of acting directly on the environment, however, the high–level system adjusts the desired states for the control systems at the next lower level of control hierarchy. This process is repeated until the control mechanisms at the lowest level actually interact with the environment. [Ref. 6:p. 35] This is called a hierarchical control mechanism that is on the vertical chain of command line. But each desired states assigned to its subordinate C^3I system requires different decisions and actions. These multiple decisions and actions from different subordinate C^3I system levels can cause the overlap of effects over the entire environment in the higher level. This overlap imposes on their mutual superior the requirements that higher level C^3I system avoid setting goals or desired states for his subordinates which put them in contention. It is the superior's responsibility to see to it that his air–defense people do not shoot down his own returning strike aircraft. Figure 2.3 shows both hierarchical control over vertical C^3I systems and mutual coordination connectivity between parallel C^3I systems in real combat operations. [Ref. 13:pp. 65–69]

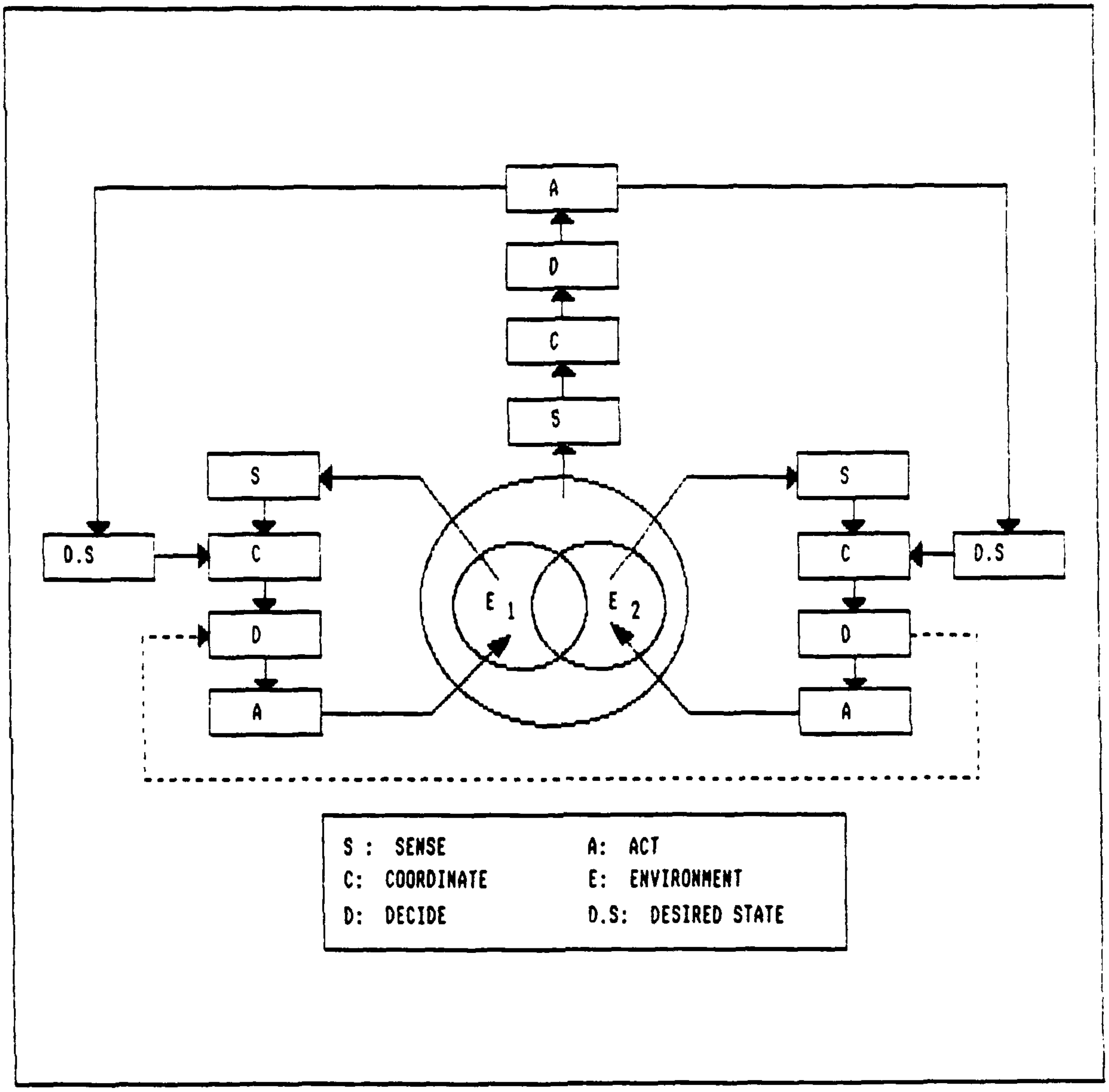


Figure 2.3 Coordination of C^2 processes

B. C^3 SYSTEM CONTEXT

The system context is defined as the total environment in which the system is expected to operate. The C^3 system context consists of all those conditions or requirements that must be satisfied by the system. The C^3 system context includes the definition of system boundaries, the system topology, performance requirements, system functions, organizational/command relationships and operating states. [Ref. 14:pp. 82–83].

1. C^2/C^3 Relationships

Remembering that C^2 is defined as "The exercise of Authority and Direction by a ..." by Joint Chiefs of Staff Publication 1 (JCS PUB 1), C^2 is considered a behavioral function. The purpose of C^3 system is to support the commander's behavior. Then the C^3 system is the means of the C^2 process, that is, an arrangement of basic elements satisfying the required functions and boundary conditions of the system [Ref. 14:p.82]. In other words, the C^3 system is defined as the technological system and its architecture that defines the interconnection of the C^3 elements. Assume that the C^2 process is the decision making process of decision makers, then the whole purpose of the physical C^3 system is to provide information to the C^2 organization and implement the decisions generated by the C^2 process. This relationship between the C^2 process and the C^3 system is shown in the Figure 2.4 [Ref. 9:p. 33].

The essential ingredients for C^3 are a commander, a mission, and the supporting C^3 system with the commander being its keystone. In terms of military decision making theory, a commander can be considered as a decision maker and controller, a mission as the desired state in its decision area, and the C^3 system as the distributed information processing system. In the previous section, however, the

Intelligence component of C^3I represents the intelligence analysis function in addition to C^3 functions. So the C^3I system may be called the "Distributed Decision Making System" including the decision maker's behavioral function, that is, the hybrid system of decision makers, states variables, and distributed information system.

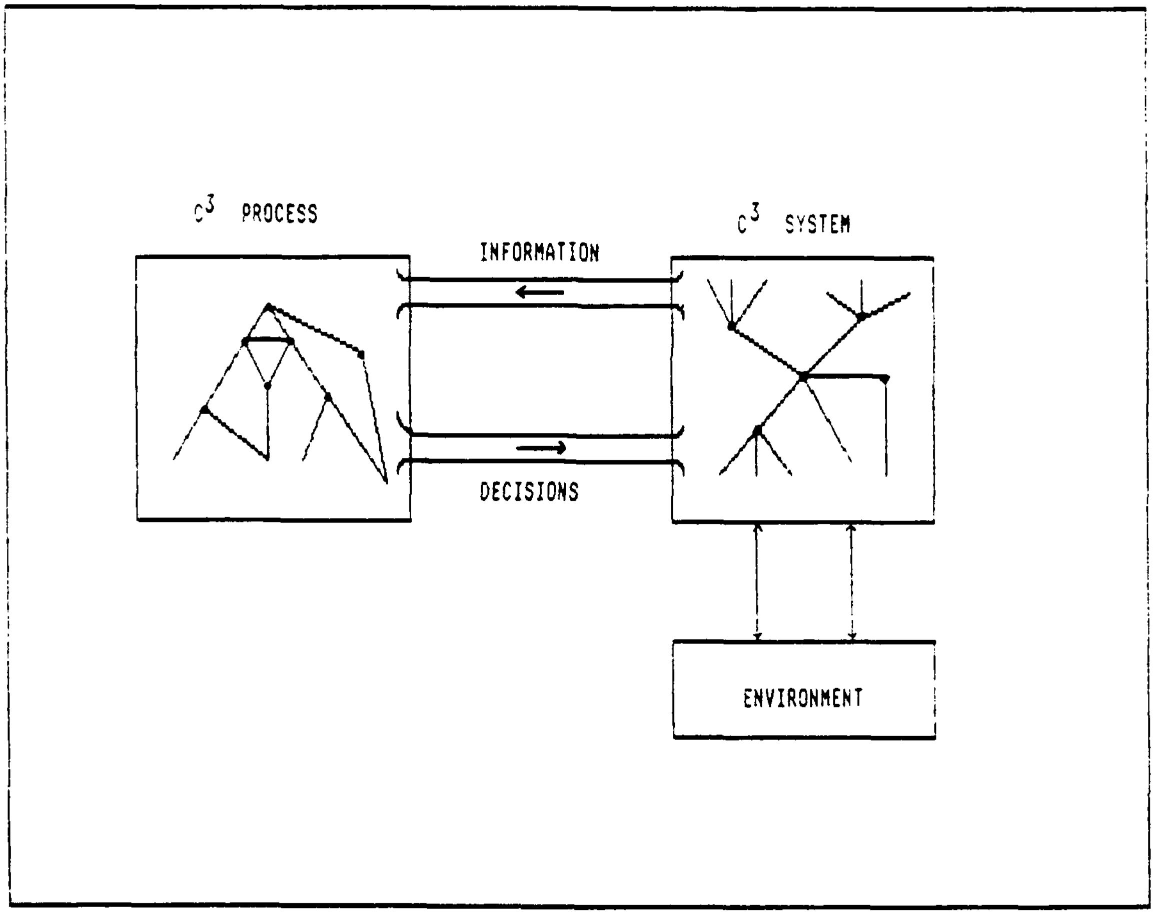


Figure 2.4 Interactions between C^2 process and C^3 system

2. C^2 Organization

To accomplish missions the commanders must establish a command and control (C^2) organizational structure that can deal effectively with a rapidly changing tactical situation. The central organic part of C^3I system is the decision agents such as commander or decision maker, or controller. In a system level decision process, the decision agents invoke a system–level decision rule to select a system–level action for a given system–level observation [Ref. 15:p. 49]. As for a C^3I system, there is more than one system level in combat operations process because the decision agents are geographically dispersed due to the environmental and survivability reasons. So the sequence of system–level observation–action pairs characterize the dynamics of the system–level decision process as shown in the Figure 2.5 [Ref. 16:p. 5].

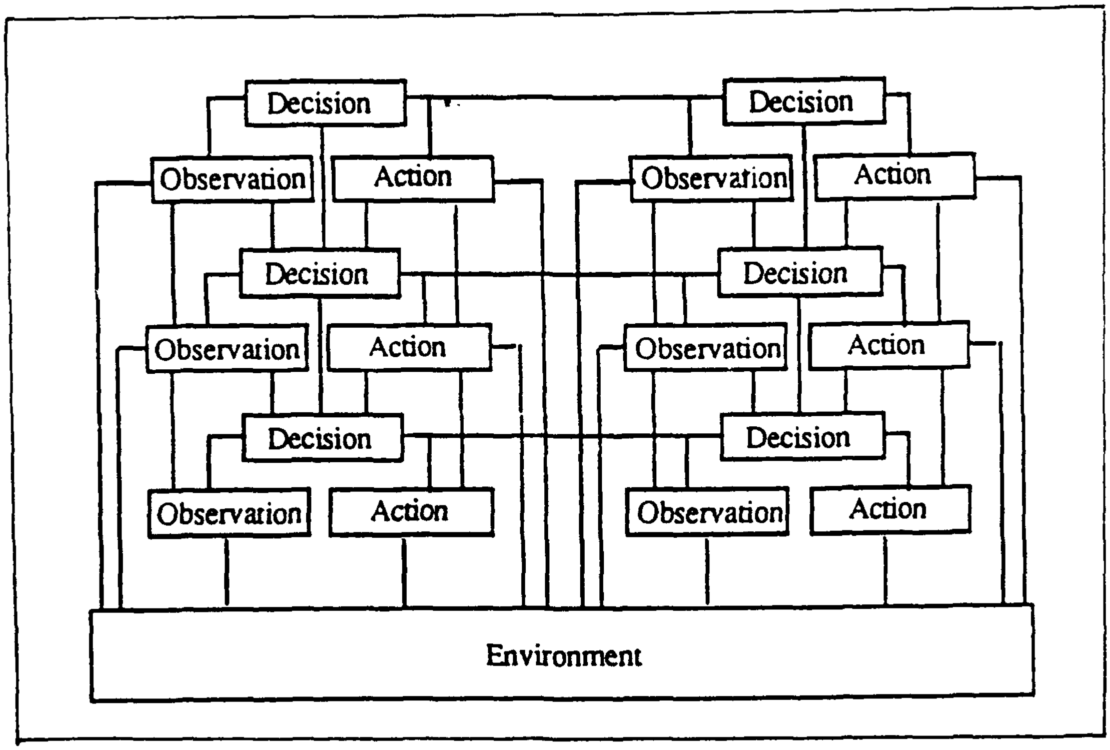


Figure 2.5 The general structure of C^3 paradigms

In Figure 2.5, actions in each system have effects on the environment, and the effect from an action from a system provides a chain of effects to another system. So the decision agent in each system has to keep the environment updated continuously. In order for this to occur, the decision agent has to absorb and interpret all the tactical information. However, different weapon systems have their unique capabilities and effects, so the decision agent must be the central organ with the capability of an a true expert tactician and technician for a specific weapon system. Finally, the decision agent must have a sufficient amount of time to correlate correctly the real–time information with the tactics that it has stored in its brain to arrive at the correct decision [Ref. 9:p.33]. The necessary C^2 organizational structure is very much dependent upon sensors, communications, and weapons technology [Ref. 17:p. 21].

But the behavior of one human decision maker is not capable of all of these tasks due to the limitations of Short Term Memory (STM), Learning Time, Long Term Memory(LTM), and Retrieval Time From LTM, etc. So the military C^2 system must be a multi–agent organization. Figure 2.6 shows the Multi–agent C^2 organization model by Michael Athans [Ref. 9:p.37].

The principle of this hypothetical C^2 organization model is that there must be a "team of experts" instead of a commander. The C^2 organization model consists of Principle Expert Model (PEM) and Mutual Expert Model (MEM). PEM is the tactical decision making process of an individual commander and MEM is the collective coordinated decision process of commanders operating within a C^2 organization. PEM's would define the nature and level of detail of the tactical information needed by each commander to properly utilize his expertise in his own particular area. On the other hand, MEM's would define the nature and minimum

level of aggregation of the information necessary to be common knowledge to all commanders in the C^2 organization so that suitably coordinated decisions can be made related to the location, motion, and even reassignment of the assets. This in turn would specify the subset of tactical information that must be common information to all appropriate commanders in the C^2 organization [Ref. 9:p.37]. The decision agents will use both human decision–makers and computer–based algorithms [Ref. 18:p. 6].

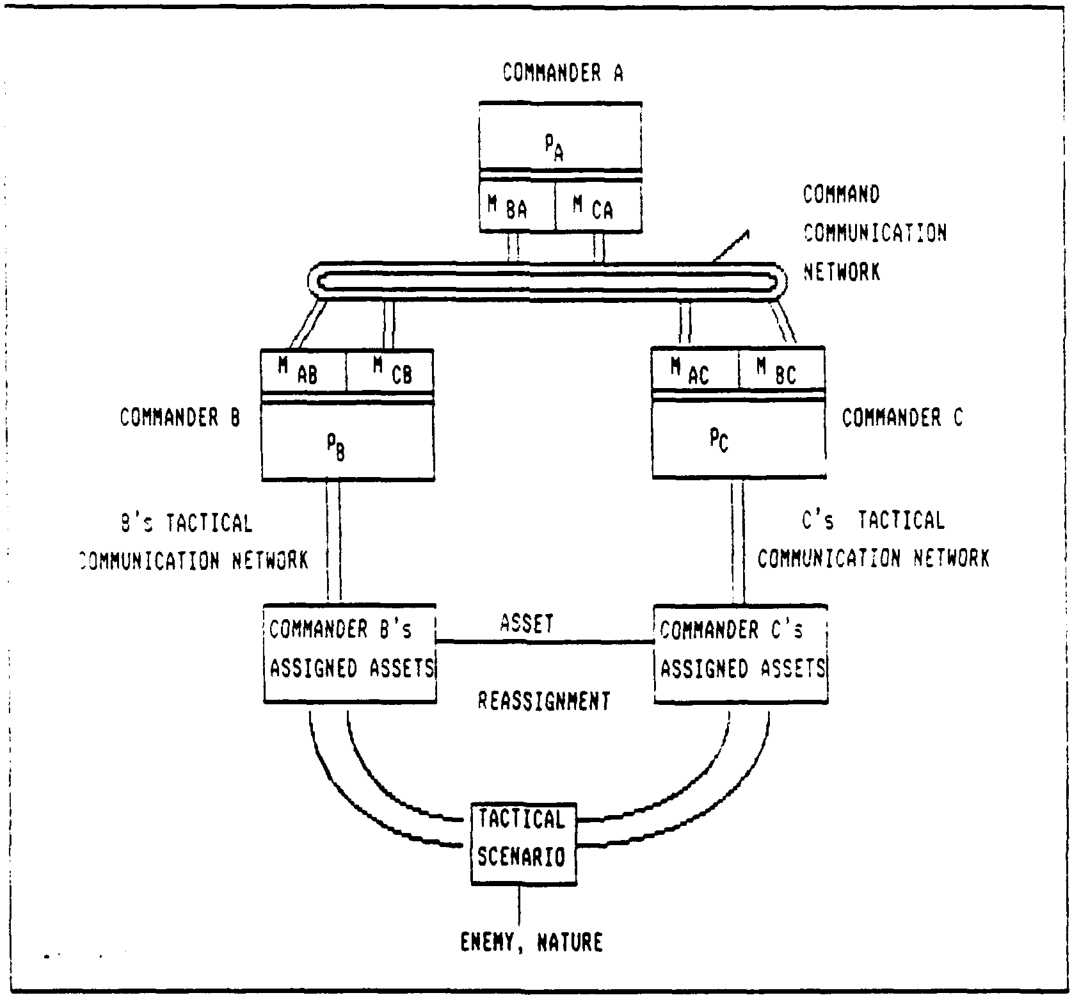


Figure 2.6 Hypothetical C^2 organization

3. Decision Making Categories

After commanders establish the C^2 organization, they will encounter some problems that require commander's decision making. Those problems will take place in three areas. During the battle, commanders continually have two questions:

- What is happening ?
- What (if anything) can or should I do about it ?

The former calls for an information decision, the latter for an operational decision or organizational decision. Operational decisions concern the employment of his forces or controlling fire distribution. Once a mission is assigned to the force, the commander will make a organizational decision, which redesigns the command structure, establishes a chain of command for the execution of his operational decisions, and also establish the structure for the flow of orders and reports as well for the intermediate processing of information necessary to support his own decision making and to some extent the decision making of his subordinate commanders. Information decisions are those decisions made by a commander as to what he believes the situation to be, in the context of the mission he is trying to accomplish. A commander's information decisions about what is happening, although often unstated, necessarily precede his operational decisions about what actions he and his subordinate commanders ought to take. [Ref. 4:p. 12]

4. C^3 System Elements

Now, the commanders have to solve the problems using the C^3 system. In the previous section, that is defined as the physical system and its architecture that defines the interconnection of the C^3 elements. C^3 elements are those items of physical and technological hardware and software that generate, manipulate, communicate, and display information and the weapon systems. The typical (physical) C^3 elements are as follows [Ref. 9:p. 31]:

- Sensors (fixed or moving)
- Communication links (mostly radio for tactical C^2) and related devices
- Computers and Displays (hardware, software, firmware, decision aids) viewed as system
- Weapons platforms and weapons system

The overall system elements will include functions from the hybrid of those hardware and software, procedures, and personnel related to operations of the system as well.

5. System Functional Components

In order to perform the entire C^3I system function, the combination of these system elements will build up some sub–functions as the task is reassigned to each sub–echelon. As a result of war games and of a detailed functional analysis conducted at Johns Hopkins APL [Ref. 19], a number of functions are identified. These functions were aggregated into six "functional areas" of the the C^2 architecture [Ref. 19:pp.10–12]:

- Command function
- Information management function
- Engagement management function
- Sensor management function
- Communication management function
- System management function

a. Command

The command function includes planning, directing, and assessing the operations of forces to achieve assigned mission objectives. Within a multiple—echelon command structure, it permits senior commanders to provide direction and guidance to subordinates who interpret, detail, and execute actions, while providing the commanders with supportive information and plans.

b. Information Management

The information management functions include acquiring, processing, and distributing data and information. The primary objective is to ensure the receipt of timely, accurate, and complete information by users. This area provides information collection, processing, evaluation, and distribution services at each command node, resulting in an up–to–date tactical surveillance picture for the area of interest.

c. Engagement Management

The engagement management functions include allocating, controlling, coordinating, and monitoring force assets that permit the execution of combat operations to support the course of action selected to meet the mission objectives. They coordinate the use of own–force weapons to maximize the destruction of enemy forces while minimizing the expenditure of resources in both offensive and defensive roles. This task requires that information, tactics, and the allocation of resources and responsibilities be coordinated among the various warfare areas, while an overall viewpoint of the engagement and its objectives is maintained.

d. Sensor Management

The sensor management functions include allocating, controlling, coordinating, and monitoring sensor assets. They support command decision making and weapons use (consistent with the constraints of the rules of engagement, emission control, and mutual interference with other sensor or communications assets by ensuring that surveillance information is provided to the information management functional area).

e. Communications Management

The communication management functions include allocating, controlling, coordinating, and monitoring communications assets. They provide the connectivity needed to implement the exchange of commands and information between or among designated force elements to allow the most effective direction of dispersed force elements.

f. System Management

The system management function include allocating, controlling, coordinating, and monitoring force assets that comprise the C^2 system, with the exception of the communications assets. The C^2 system assets include information handling systems, displays, and decision aids, among others. System management allows a commander to establish and adjust the C^2 system state, measure and assess its status, and develop options and timing for system reconfiguration or reconstruction in the event of disruption while maintaining system stability.

6. System Characteristics Requirements

The entire C^3I system consisting of these six sub–functions requires some characteristics to enable the C^3 system to perform its mission of aiding the battle commander in the exercise of command and control. These characteristics can be classified in many ways. The general system characteristics will include reliability, survivability, flexibility, responsiveness, interoperability, and

user–orientation [Ref. 20:p. 22]. But considering the tactical operations, a couple of characteristics must be considered in addition. They are mobility, security, maintainability, and risk [Ref. 21:p. 57]. But some of these characteristics will have similar definitions or sub parts of the others. They are different only based on the priority of characteristics varying the viewpoint of tactical, strategic, system engineering, or overall system descriptions. Here the overall system characteristics will be explained only.

a. Reliability

Reliability, or dependability, is defined as "the ability of an item to perform a required function under stated conditions for a specified period of time" [Ref. 22:p. 305]. Reliability, in engineering terms, means the probability that a system or component will not fail on any given trail or during any period of operation [Ref. 23:p. 129]. The reliability will be represented by availability and operability [Ref. 21:p. 50].

b. Survivability

Survivability is defined as "the measure of the degree to which C3 equipment items and system capabilities will be able to withstand either natural or man–made hostile environments without suffering abortive impairment of its ability to accomplish its designated mission" [Ref. 24:p. 676]. Survivability of C^3 systems can be related to the ability of our C^3 systems to first of all withstand the initial attack, and secondly to be able to recover and reconstitute immediately thereafter [Ref. 21:p. 47]. Survivability can be achieved by hardening, redundancy, dispersal, and mobility [Ref. 25:p. 26] and also by deception and durability of parts [Ref. 21:p. 49].

c. Flexibility

Flexibility is defined as "the ability of C^3 systems to be responsive or readily adjustable to changing conditions or situations". Flexible systems or equipment are not limited in capabilities, but have the inherent ability to be able to operate successfully under a variety of conditions and situations. In addition they must have the ability to expand, contract and/or reorganize in such a manner as to satisfy a wide range of user demands and requirements. The flexibility will be represented by expandability and adaptability. [Ref. 21:pp. 45–46]

d. Responsiveness

A C^2 system must respond quickly and accurately to provide the commander with essential information in a timely manner. In crisis situations, time becomes the the critical factor. Time–late information is useless information. [Ref. 25:p. 27]

e. Interoperability

Interoperability of C^3 systems and subsystems is critical to the success of military operations, especially in joint and combined operations. JCS PUB 1 defines interoperability as "the ability of systems, units or forces to provide services to and accept services from other systems, units or forces and to use the services so exchanged to enable them to operate effectively together". It's beyond the "compatibility" that is merely the ability to "function in the same system or environment without mutual interference". According to a briefing notes from Armed Forces Staff College: Principle of Command and Control (Unpublished), compatibility is the "technical sameness," and interoperability is possible through the compatibility, information standards, and procedures.

f. User–Orientation

A C^2 system must be designed for the user. Information must be readily accessible in a format usable by the commander and his staff. Displays, graphics, and decision aids should not require extensive analytical interpretation. [Ref. 20:p. 22] Standardization and simplicity will be the design factors for user–oriented system [Ref. 21:p. 52].

C. C^3 INFORMATION SYSTEM

A C^3I system is essentially an information processing system, if the behaviors of human decision makers in organizations, which is defined earlier, is excluded . The primary purpose of the C^3 system is to reduce the time–uncertainty product. Then what is the C^3 information system and how does the system work ? In this section, that system will be defined from the perspective of information system for command and control rather than Computer–Based Information System (CBIS).

1. Background

a. Uncertainty and Information

In a previous section, uncertainty was defined as the difference between the required information to carry out a mission and the available information at a time. In fact, information itself is not enough to describe this. There are degrees of accuracy in information itself. Restrictively speaking, the decision maker needs not information but the knowledge to make a decision. But it is not always possible to get the knowledge. So the decision maker adapts the information with a high probability of accuracy as the decision making factors. Now let K_d represent the knowledge to carry out a mission, or solve a problem, or make a decision effectively, and let K_s be the knowledge that a decision making entity has

at the point in time and place that a choice needs to be made. Then, uncertainty can be defined as the difference between these two quantities,

$$U = K_d - K_s ,$$

namely, the difference between what one needs to know and what one knows [Ref. 5:p. 7].

Now what is the difference between information and knowledge? What is different from data? Data are facts which are independent, unrelated and unlimited in number. Information is the organized, intelligible and meaningful result once data are processed and evaluated. Information adds to relevant knowledge, reduces uncertainty and supports the decision making process in an organization. [Ref. 26:p. 11] Data are transformed to information, primarily by technological processing: an electromagnetic pulse is converted into a set of symbols on a radar screen. Transformation of information into knowledge is, however, a cognitive process that is done by humans. Figure 2.7 shows the relationships among those three things. [Ref. 5:p. 7]

Data

|| <= Technological

Information

|| <= Cognitive

Knowledge

Figure 2.7 Data, Information, and Knowledge

Information is a resource which can change a decision or state, lead to act on, and have meanings [Ref. 27]. The value of information depends on analysis, interpretation, explanation, and finally, understanding [Ref. 28:p. 19]. This means that information can be used to make a decision as well as gain knowledge after processing them in a proper way. Information systems support decision makers by way of analysis, interpretation through the correlation and the best presentation, then decision makers will be able to understand the diversity of information and make a decision. Decision makers may be either human or a computer algorithm, or both depending on the context.

b. Information–Organization–Decision Loops

Organizations exist to serve human needs. They help individuals accomplish things that normally could not be done alone. Therefore the organization serves as a medium for acquiring knowledge or information that can be used to make decisions for reaching an objective [Ref. 26:p. 17]. Organization is organized through its information processes; thus the organization produces the information system and *vice versa*. An action involving several actors in an organization results in the production of information appropriated and stored by the group. But in military organization, information is produced by the enemy organization as well. That is the reason that the military organization needs the cybernetic control system.

In the Organizational Information System (OIS) Model (Figure 2.8) presented by Moigne and Sibley [Ref. 29:p 241], however, OIS allows the organization to represent itself and define its data, its behavior, and its transformations with the means of controlling the information process (in the sense of controlling the collection, production, and use of the data). So if the identification

of information process (the production by the organizational action or flow from external sources) is ignored, the OIS model is a good systemic approach to *information–organization–decision loops.*

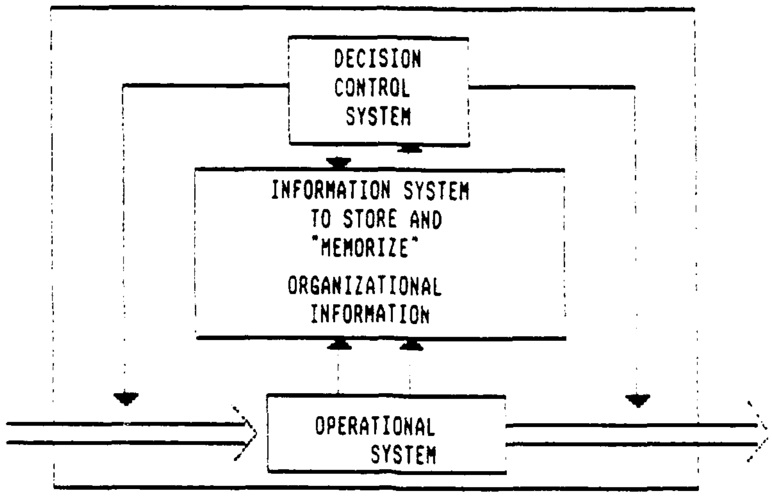


Figure 2.8 The Systemic Model of the Organization and OIS

The systemic model has the great advantage of allowing two different viewpoints of organization and information: production and memorization. The interaction of the system with the environment and other processors (input and output) normally involved formatted data. The system needs to retain some memory of its transactions. Data generated by this behavior are called *generic information* [Ref. 29:p. 242]. The other information transmitted from the external source will be called *circulating information.* Generic information belongs to the organization that creates them. The other viewpoint is the memorization of information. On the other hand, production of information demands a method for its storage (and thus its corporate memorization). Memorization is more than mere

retention and storage; other functions include its addressing, indexing, classification, updating rules, etc. Thus a database management system (DBMS) is merely a somewhat constrained aspect of the OIS [Ref. 29:p. 242].

The relationship among information, organization, and decision is that the organization produces information by either its own production function such as generic information generated by the group's behavior, or external flow of information such as circulating information, then the decision and control system in an organization makes a decision by processing the information through information system which manages the collection, manipulation, storage, retrieval and presentation of information to user, and finally controls the organization to obtain the objective.

2. Command and Control Information System (CCIS)

a. *Utility Functions of* CCIS

Once information is obtained, the information is used in every stage of the command and control process. The command process model (Figure 2.9) by Holman and others in their research "The Specification of Surface Naval Command System", shows the continuous impact of information on the command process [Ref. 30:p. 23].

The value of the information system is its ability to characterize the event or process it describes. And the ability of the information system to adequately describe an event or process is directly related to its utility. [Ref. 31:pp. 249–250]. But, the information system for command and control can not be a single utility program. It must be an integrated utilities support system to support all those needs of information in command process. The functional relationships of CCIS with its user and its activities is shown Figure 2.10 [Ref. 32:p. 157].

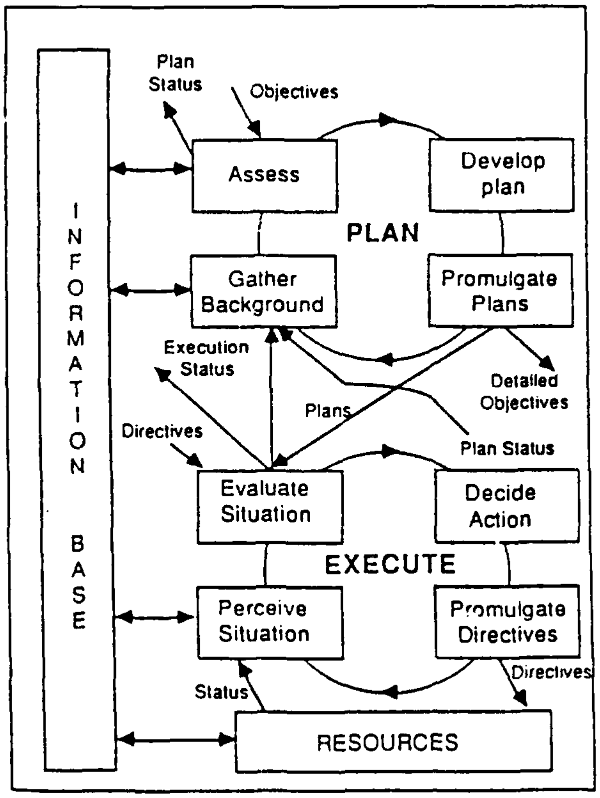


Figure 2.9 The Command Process Model

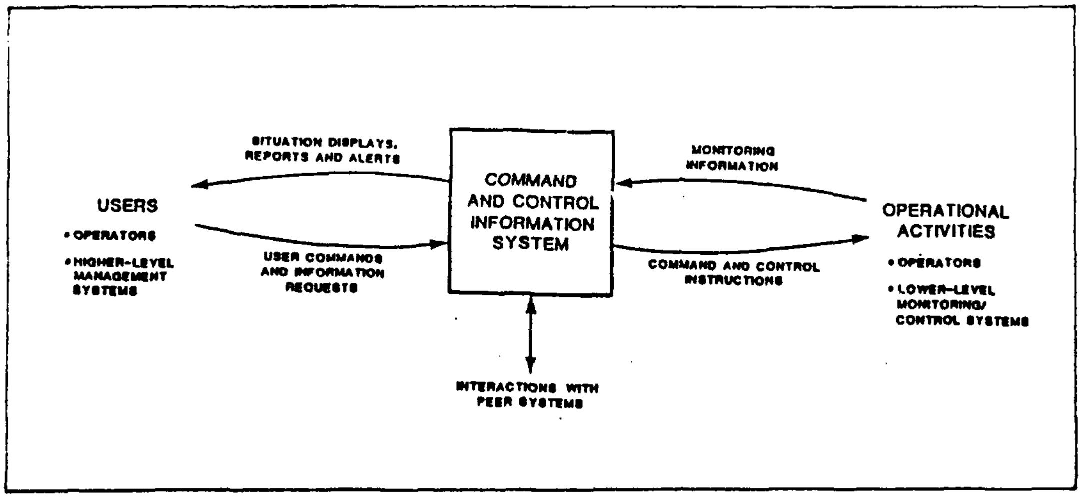


Figure 2.10 Functional Schematic Diagram of CCIS Relationships

Computers are used as aids both in the information gathering stage and in the operational stage of decision making. And each organization has its own operations and requirements of information, so each organization could determine its computing requirements, the size of computer appropriate to its function and its internal user group in an organization. Also when a node determines that it possesses information that may affect the overall mission at another node, it will then broadcast that information to those nodes that may be affected. Also, if a node requires information that it knows another node may have, it will transmit a request for those data. CCIS in each organization has to have its own computing size, various utilities, distributed networking architecture. Figure 2.11 [Ref. 32:p. 158] shows the utilities of CCIS, user interface, network interface, etc.

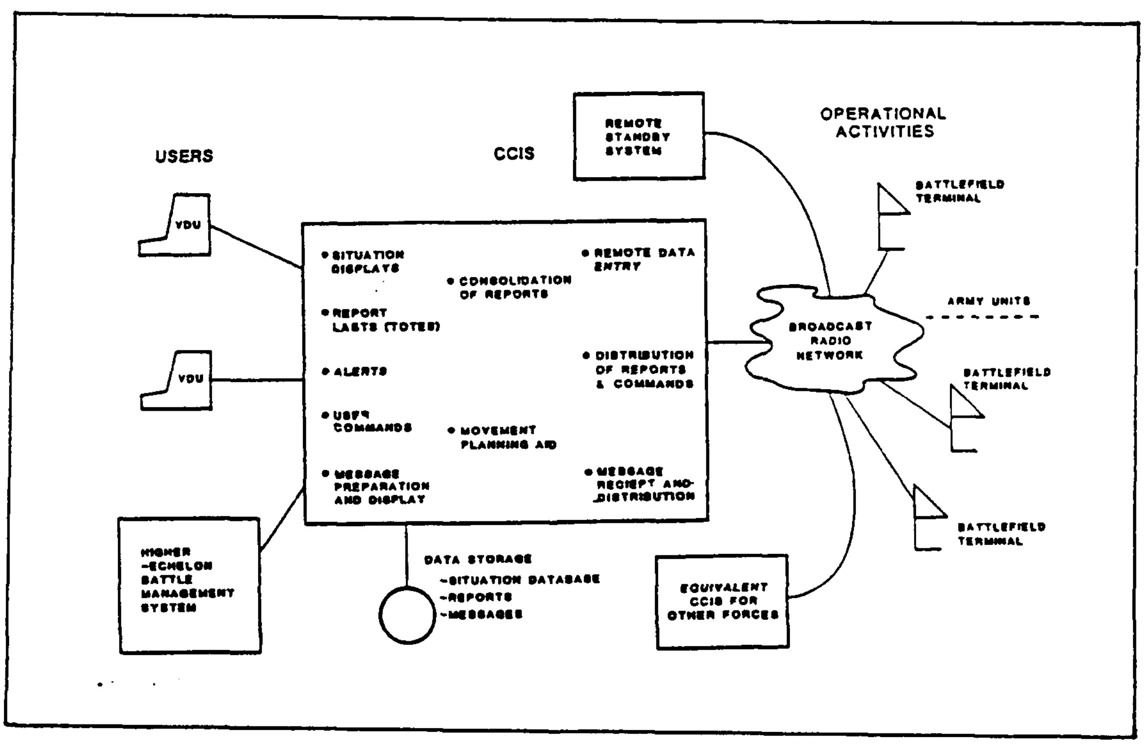


Figure 2.11 CCIS in the Role Military Battlefield Management

b. User Interface Functions of CCIS

In a previous section, it was said that the value of information depends on the interpretation and decision maker's understanding. The ideal model of decision maker would be the computer system that has the human intelligence capability or human beings who has the computing rate and memorizing capacity as same as the computer system. But, it is not possible to build a computer system with the human capability with the current state–of–the–art. So the alternative solution is to build the Decision Support System rather than Decision Making System using computers, that is, the hybrid decision making system of human intelligence capability and computerized memory capacity and computing rate. This is possible through the close interface between humans and computers. In DSS, the interface function between the CCIS and human decision makers will be designed for the best interpretation and understanding of the state. Then CCIS will have the decision support capability. In addition, computers are used as aids to the decision process itself. The relationship between computer and user is shown in Figure 2.12 [Ref. 33:p. 270].

3. Information Presentation

The ability to quickly and easily display geographical and tactical data in various graphical forms and perspectives is a technology that has come of age. The digital data bases that are offered by the Defense Mapping Agency are providing separate addressable digital information such as terrain, elevations, road conditions, city locations, etc., that is needed for developing such graphical display. Together with the use of icons, mouse and touch screen technology, graphical displays will find increasing use within decision support systems in representing situation assessments as well as planning and resource allocation. [Ref. 34:p. 218]

The use of voice to control the interactive graphic displays, to query the knowledge base and to provide data reports to the decision support system is a major technological means to the interface technics.

Of course, the conventional technology using text and tabular form, alarm mode, color, etc. will be used for information presentation as well.

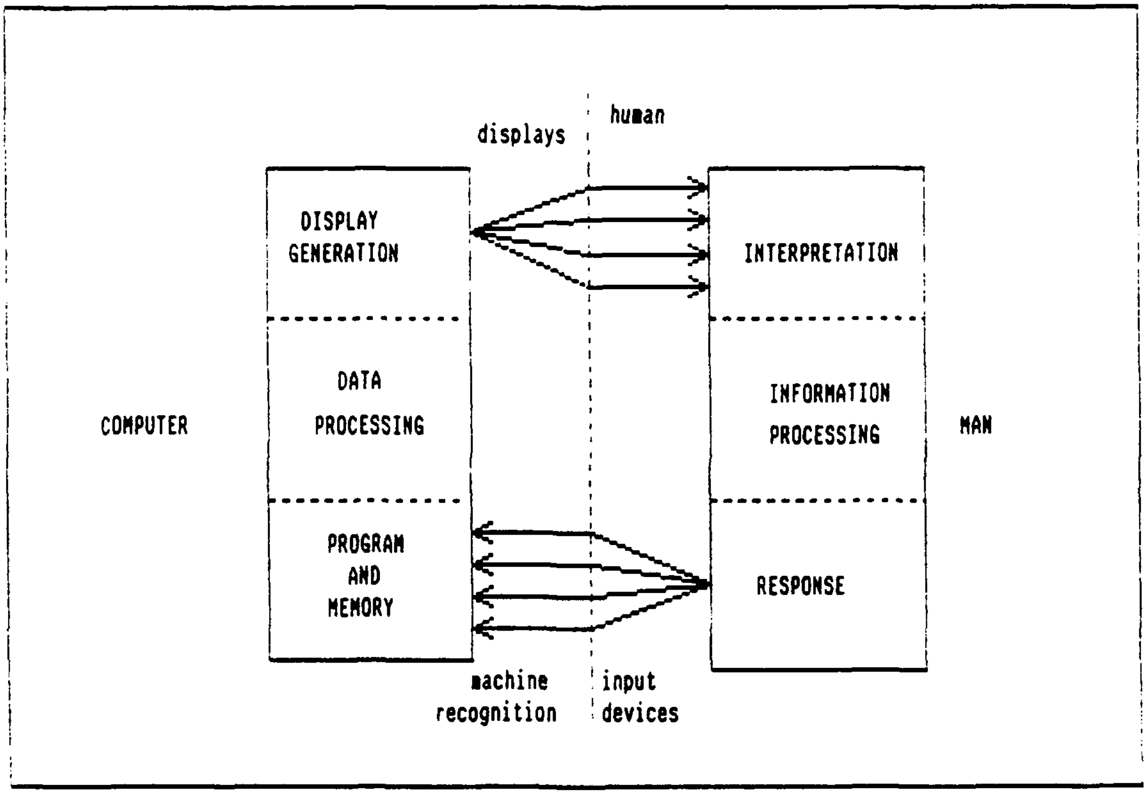


Figure 2.12 Man–Machine Interface to Meet DSS Needs

D. C^3 ARCHITECTURE

The architecture of C^3 system is the initial stage of the overall system engineering process. Architecture is the arrangement of (or process of arranging) the basic elements of a C^3system into an orderly system framework. [Ref. 14:p. 82] It is composed of functions, structures, connectivities, and interfaces. [Ref. 19:p. 13]

One of the characteristics of a C^3 system architecture is that it describes the interrelationships between selected elements of the system. These C^3 system elements are functions, facilities, equipment, communications, procedures, and personnel. [Ref. 14:p. 82]

The purpose of architecture is to build a system using some resources and materials. For example, One use wiring for electricity support, plumbing for water support, walls and roofing for protection from hostile circumstances like animals or wind. [Ref. 14:p. 82] So the function of architecture is to "map" the elements to its function. In other words, architecture means the translation of function into form. And the system architecture includes the clear identification of subsystem, the allocation of functions to subsystem, and the establishment of the interrelation through standards for interfaces between subsystems [Ref. 4:p. 85].

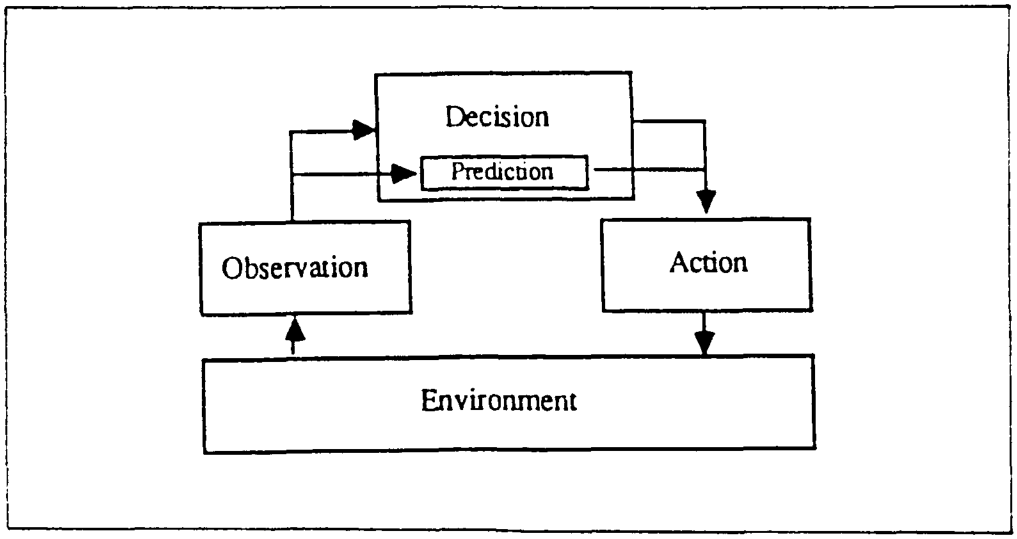
1. Classifications of Sub–System

The C^3 system varies depending on the mission and type of forces. The sub–system of C^3 system will also vary depending on each overall C^3 system itself in turn. But the subsystem will be classified through the functional decomposition of C^3 system. A subsystem is a subset of system resources including their imbedded dynamics. The general functional basis used to divide the C^3 system into subsystems, thus, can be the observation subsystem, the decision subsystem, and the action subsystem which describe the dynamics as shown in Figure 2.5 above.

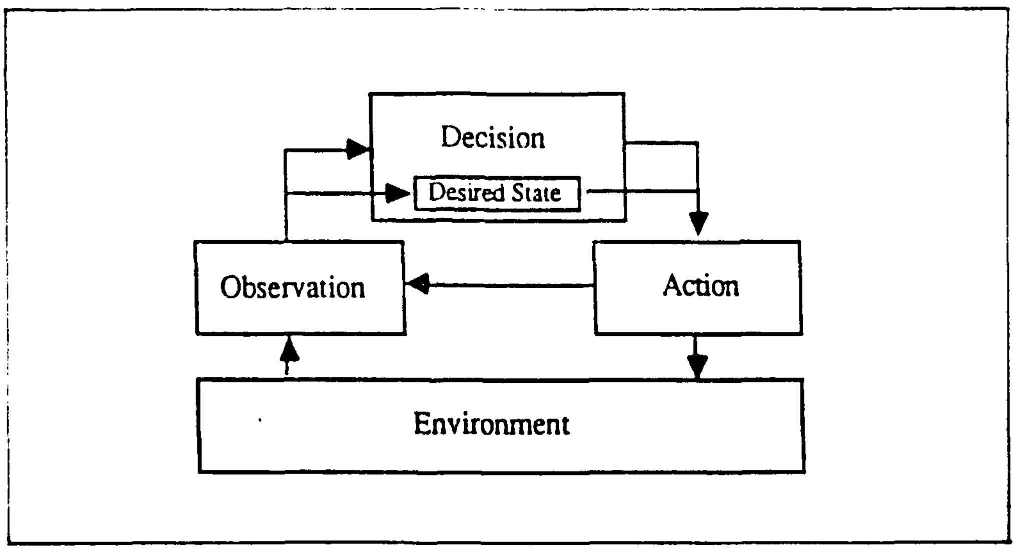
The observation subsystem is the collection of all resources which are involved in making observations with regard to other resources and the environment. The action subsystem is the collection of all resources which are involved in executing actions which may impact on other resources and the environment. The decision subsystem is the collection of all resources involved in

making decisions, i.e., those resources responsible for deciding how to best utilize the observation and action subsystems to accomplish the mission evolving from the conflict. These subsystems may then be decomposed into specialized subsystems for different phases of observation, decision and action which may occur sequentially or in parallel as shown in Figures 2.13.a and 2.13.b. Each of the blocks represent a complex, collective and compound process [Ref. 16:pp. 4–6].

Once the C^3 subsystems are identified, then the C^3 system's six functions will be allocated to each subsystem in the context of system boundary. But architecture is not a set of functions or a partitioning of these functions into subsets. Also it's not a set of standards, protocols or procedures for the system. However, the architecture can be expressed in terms of warfare and command functional relationships, network diagrams, connectivity charts, information flow diagrams, design guidelines and standards [Ref. 14:p. 84]. The basic building block of architecture is the structure and connectivity.



a). Main cycle with Feed–forward



b). Main cycle with Feedback

Figure 2.13 General Structure of C^3 Process

2. Basic Building Blocks: Functional Relationships

A generic building block of the C^2 architecture consisting of six functional areas and the functional connectivities among them is shown in Figure 2.14.

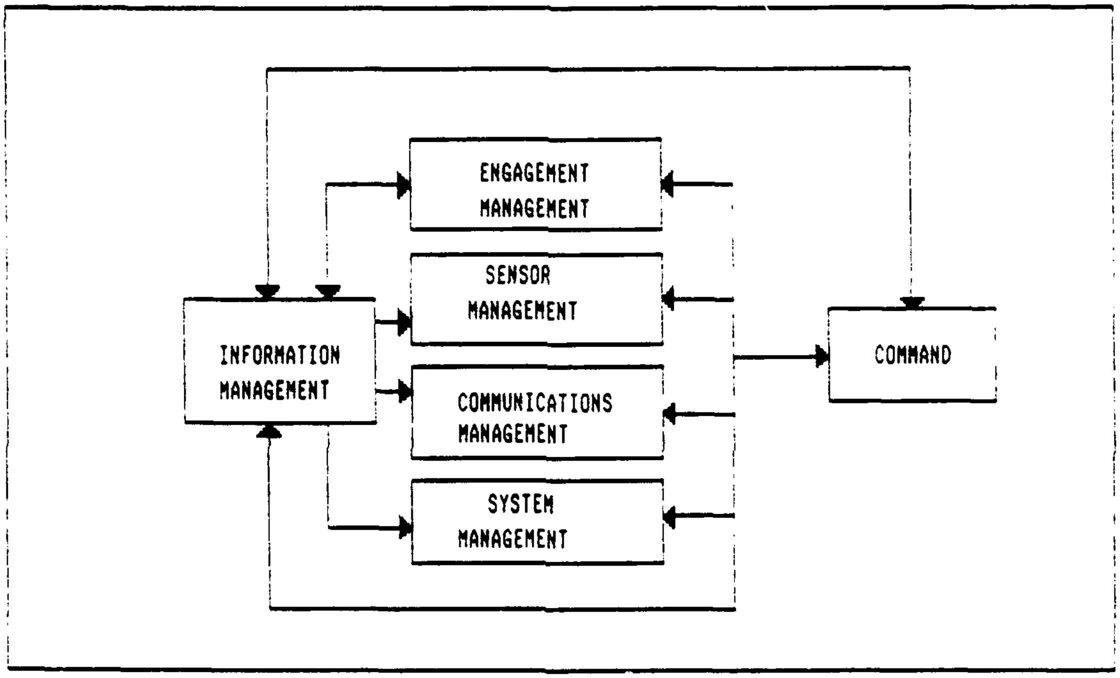


Figure 2.14 Functional Connectivities

The connectivities among the six functional areas have been defined as follows [Ref. 19:p.12]:

- Command – The connectivity that allows a commander to direct and control his forces;
- Coordination – The connectivity between functional areas required to ensure that assets are employed in accordance with command guidance;
- Information Exchange – The transfer of data and information items among the various areas to support the needs of the six functional areas.

> The command portion of the command and coordination connectivities allows a commander to exercise his authority and the functional areas to respond to his direction. The coordination portion allows engagement, sensor, communications, and system management areas (the implementation arms of command) to interface with one another (in accordance with the guidelines established by command) and with command during the planning and implementation process. Two–way information flow connects each functional area with information management. That information flow provides for the transfer of data and information within the command level, allowing an information base to be developed and maintained and its contents disseminated. [Ref. 19:p.12]

Those six functions will be connected to each other through three connectivities to be allocated to the subsystem. Once they are connected in a way, they will have their own C^2 functions corresponding to each subsystem. That may be called the system level architecture of C^2 process. Those functions in terms of C^2 process will be information management, decision management, and execution management [Ref. 25:p. 126]. Figure 2.15 shows the conceptual architecture of those C^2 process. The conceptual architecture of the C^2 process presented here is a result of a study performed in 1986 by the Armed Forces Staff College as described in "The Conceptual Architecture and its Value" prepared by Major Patrick T. Thornton, USA. The architecture consists of the general flow of information and information processes which occur through three functional areas of the C^2 process. [Ref. 25:p. 141] The next question is what is the basic structure of the function.

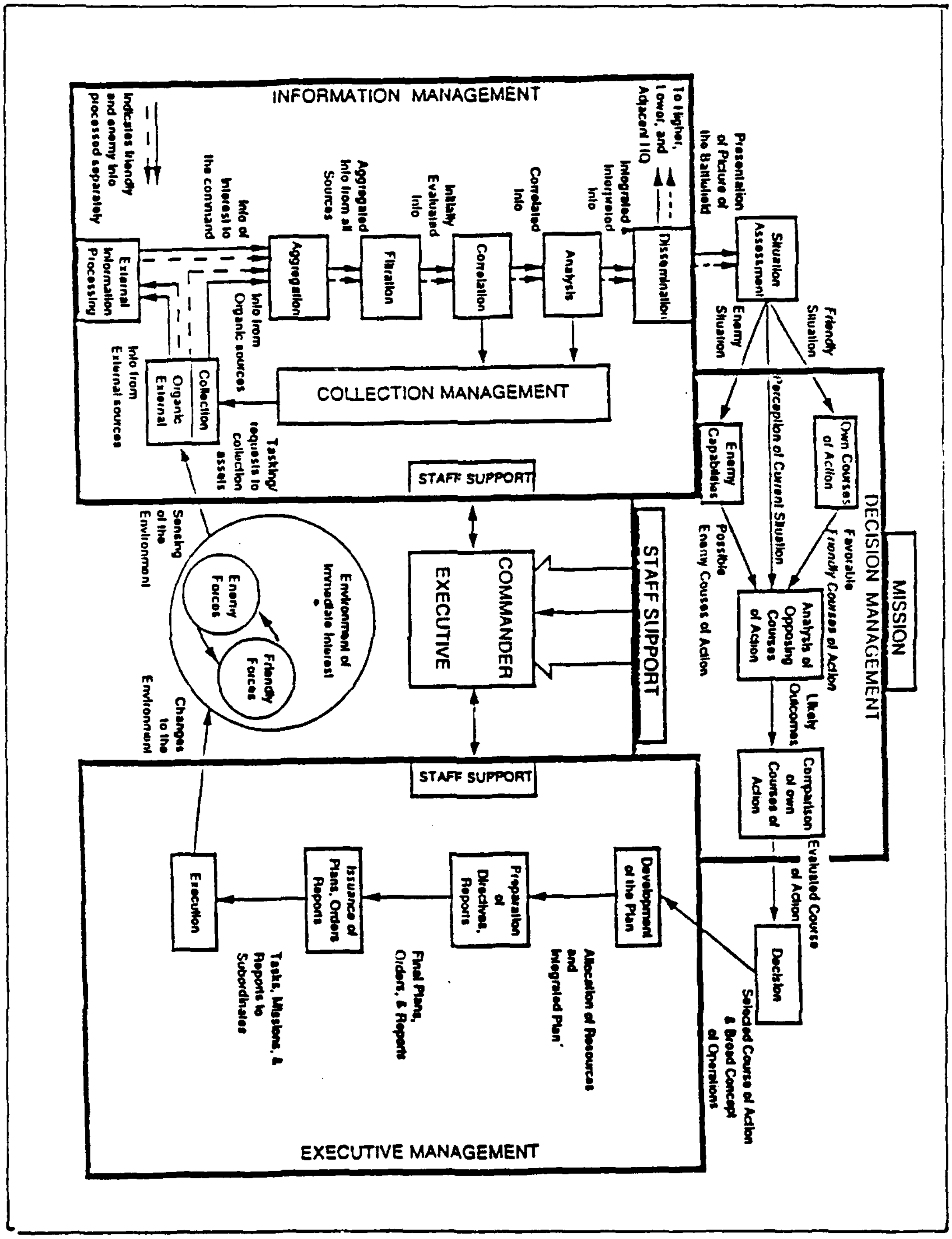


Figure 2.15 Conceptual Architecture of the C^2 Process

3. Hierarchical Structure of a Functional System

The structure of a functional system will describe how a function is constructed, and also define the limits of centralization and decentralization of control. A hierarchical structure of a generic C^2 system was explored in detail over four levels in terms of the defining features at that level by Coe and Dockery. [Ref. 35:p. 22]:

Level	Defining Feature	Focus
Micro	Data	Nodes
Meso	Structure/Information	Links
Meta	Rules/Transaction	Processes
Macro	Goals for the C^2 system	Functions

The four level structure can be used graphically to build a generic C^2 structure such as those shown in Figure 2.16 [Ref. 35:p. 23].

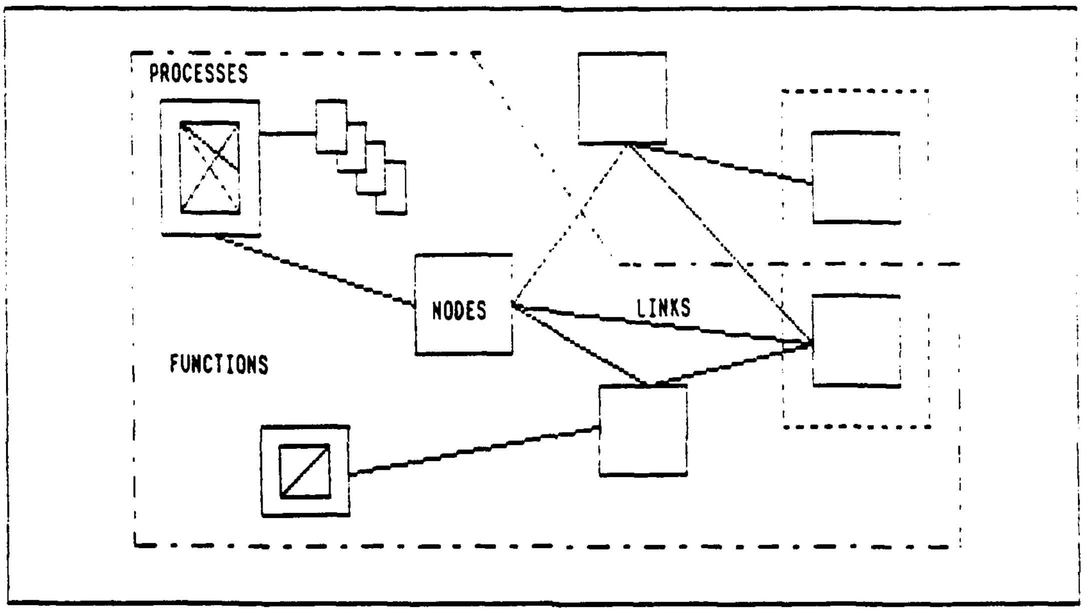


Figure 2.16 Hierarchical structure of a generic C^2 system

Each of these levels can be translated through its operational description and defining features into a firm and ongoing program of theoretical studies. [Ref. 35:p. 23] Once a framework of function is constructed, a couple of functions will be combined through connectivities and interfaces to support a subsystem.

4. Connectivity and Interface

Connectivities are the means for command, coordination, and information flow within the C^2 system. A similar flow to and from external entities occurs via interfaces [Ref. 19:p.13]. The concept of connectivity leads to questions concerning the connectivity of procedures and training and their influences on system design, and the perspective on connectivity is extended from a one–dimensional to a multi–dimensional view, freeing us from a purely communication representation bias. The multiple approach to expanding the definition of connectivity is illustrated in Figure 2.17 by contrasting communications *connections* with C^2 *relationships* [Ref. 35:p. 23].

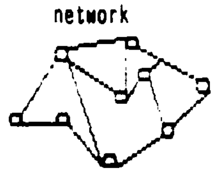
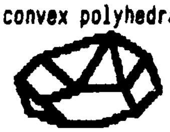
ISSUE	TOPOLOGICAL STRUCTUE	ANALYTICAL SOLUTION	REAL-LIFE INTERPRETATION
communications links and nodes	network 	linear program	shortest path
C^2 relations A commands B C reports to D E communicates with F G is a tgt of H	convex polyhedra  in N-dim space	directed graphs Q-analysis petri-nets	patterns structure rigidity weighting transmission speeds

Figure 2.17 Two views of connectivity

5. Types of Architecture

So far the architecture is viewed in terms of functional relationships. But, in military organizations like the Army, Navy, Air Force and Marines, each echelon down to its primitive resource unit provides a service to its parent/command organization. And each echelon may be regarded as a complete C^3 system with a corresponding C^3 structure. The size of C^3 system, thus, depends on the organization as well. So this functional architecture is not enough to describe C^2 system. There are three general types of architectures currently used to describe C^2 system. They divide the overall architecture into three distinct architecture: organizational, functional, and physical. [Ref. 25:p. 128]

The organizational architecture will be represented by the command structure which will describe the chain of command, the C^2 authority and responsibility, and the relationships of the various level of command. The functional architecture performs a functional decomposition of the various mission areas presented in the organizational architecture. The physical architecture represents the specific hardware systems and their physical relationships. [Ref 25. :p. 129]

Also there must be a different levels of architecture corresponding to its size. As system developers specify from the top down and build from the bottom up, the same applies in an architecture. From the standpoint of architectural specification, one must know the architecture of next higher level (or, as a minimum, the plug–in points) before developing the architecture for a given level. There are levels of architecture to be specified depending on the boundary of the system: processing, nodal, network, and global architecture. [Ref. 14:p. 83]

Processing architecture is the architecture of the system processing elements. Examples include serial or parallel computer architectures and electronic

or photonic technology processors[Ref. 14:p. 83]. In the bottom level of architecture, it has the common identity as the physical type of architecture.

Nodal architecture is the architecture of the individual nodes itself. A node can be a facility space like a command center, a command like a battle group, or a platform like an aircraft carrier, or destroyer. The nodal architecture provides a blueprint of the relationships of the basic system elements of the node. For example, a node could have a fully distributed architecture, a partially distributed architecture or a centralized architecture [Ref. 15:p. 83]. This level of architecture will be the key point of C^2 organization design of organizational architecture.

Network architecture is the relationships of the nodes to each other and the means by which they are connected to form larger operational units or networks [Ref. 14:p. 83]. In this level, the architecture will represent the command relationships like those of hierarchical, parallel, supporting, etc. in organizational type architecture, and also describe the control types of open loop control or closed loop control. On the other hand, in this level, the decomposed functional C^3 system of functional architecture will be integrated.

Global architecture is the interconnections between networks to form a global network. It is, in essence, an architecture for a network of networks [Ref. 14:p. 83]. The total system can be characterized as a network of "nodes" and "links". So once the organization and missions are defined, the nature of C^3 architecture can be illuminated by considering the way that computers can be interconnected at a distance through telecommunications system.

6. C^3 Reference Model

This interconnection ought to be designed in such a way that modifications to portions of the total system can be made in the future without

doing violence to other portions. The solution has been to divide the end–to–end connection into seven clearly–identified "layers". That is the Open Systems Interconnection (OSI) established by the International Organization for Standardization (ISO) [Ref. 4:pp. 87–88].

The OSI's modular framework provides for the transfer of data among application processes today, while retaining the flexibility for incorporating advancing technologies in the future. In order to provide the framework of choice to guide the development of a consistent set of standards and specifications for interoperability and to offer substantial protection of extensive investments in acquisitions by being conducive to the promotion of modular reusable technologies the C^3RM (Command, Control and Communications Reference Model) was developed by Joint Directors of Laboratories, Technical Panel for C^3, C^3 Research and Technical Program [Ref. 16:p. 1].

The structure of C^3RM is shown in Figure 2.18. C^3RM describe a framework for modularizing interoperability among resources which must be networked to comprise C^3systems. It includes the ISO OSI RM by adopting it for the communications types of interactions.

The C^3RM shows three generalized canonical dimensions of C^3 architectures: resources, interactions, and conflicts. The mission of the C^3 system is a primitive notion which defines the goal, aim, objective, purpose, intent, decision requirements, function, or desired state of the C^3system. The mission must be derived from the conflict in which the C^3system is involved [Ref. 16:p. 7]. That's why the conflict is involved as one of dimensions. The highest structure of the model is the layered structure of conflicts. The intermediate structure is the layered structure of the C^2 applications which try to resolve the conflicts. The lowest

structure is that of the layered assets. The assets are utilized by the C^2 applications to interact with other sources in the environment. In a sense, the C^2 applications mediate between and among assets involved in a conflict. [Ref. 36:p. 16.2.2]

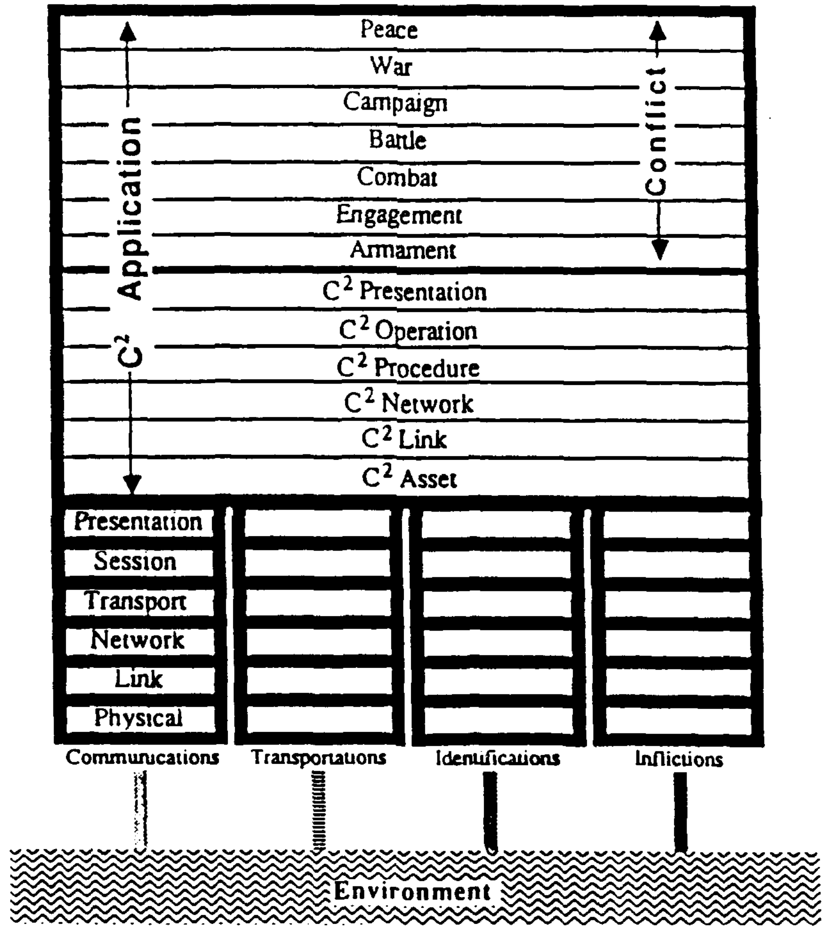


Figure 2.18 An Autonomous Multi–Interaction Resource

In terms of C^3 networked architecture, the key point of the C^3RM is the interaction dimension because C^3RM embraces analogous architectures for all the key types of physical interactions and utilizes the application layer to provide

command and control over all types of interactions in an integration fashion. The four fundamental types of interactions are identification, communications, transportation and infliction. Identification is an interaction which directly results in the recognition of objects in the environment. It's used to determine the stages, phases and targets required for each layer of conflict. Communications is an interaction which directly results in an exchange of information. It is used to command, control and coordinate between and among the resources. Transportation is an interaction which directly results in the motion of objects. It is used to carry, supply, strengthen, equip and/or load the resources with the necessary personnel and materials. Finally, infliction is an interaction which directly results in the destruction, damage, degradation or disruption of objects. It is used to destroy, damage, degrade and disrupt the capabilities of the targets involved in the conflict. [Ref. 36:pp. 16.2.2–16.2.3]

E. THE OTHER VIEW OF C^3I : C^3CM

Intelligence support to a commander is a vital part of the combat process. In Lawson's model of command process, the intelligence process can be thought of as a sense function that tells the commander what is going on in the environment. This sensed data will be compared to its desired state after undergoing process. Then the commander will decide on a course of action that will bring him to closer to its desired state, and finally the commander will take a proper fire distribution action. In combat operations, there is a continuity of operational processes from sensing to fire distribution. Briefly, the battle management system consists of intelligence from sense function, fire from the force, and the command, control, and communications components between the sense stage to act stage. If those components are well organized, the power of the force will increase, otherwise, it will decrease.

1. Force Multiplier or Divider

Assume that the performance level of each C^3I component is represented by the ratio of current capability over ideal perfect capability with the value of 0 to 1. That is:

$$P_{(i)} = \frac{\text{Current Capability of } C^3 \text{ Component}_{(i)}}{\text{Ideal Capability of } C^3 \text{ Component}_{(i)}}$$

where

$P_{(i)}$ is the performance level of each C^3 component.

Then the power of friendly force will be driven by the following formula:

$$\text{Power Driver} = f\left[\sum_{i=1}^{n} P_{(i)}\right]$$

where

$P_{(i)}$ is the variables derived from the definition of C^3 boundary.

The f function is, however, at least neither additive nor multiplicative. Assume that the communications system is down at a specific time, then there is no effects from the current C^3 system directly to operate the forces, that is, the effectiveness of the C^3 system is zero. In other words, the f function has a multiplicative function partially. But there is still a power driver to operate the force. So the definition of C^3 component as a power driver is not limited to only the four components. There is another power driver which looks like a self maintenance power of an organization when there is a malfunction which affects the

organization's operation. In military organizations, that may be a kind of inertia operator from accumulated experiences and training. Let this inertia power be α, then the f function may be represented with both additive function and multiple function including another variable α in addition to the basic C^3 components. Assume that there are simply command, control, communications, and intelligence components in the definition of a C^3 system boundary, then, the variables $P_{(i)}$ will be

$$P_{(1)} = P_{cmd}$$
$$P_{(2)} = P_{ctl}$$
$$P_{(3)} = P_{comm}$$
$$P_{(4)} = P_{int}$$
$$P_{(5)} = \alpha$$

Then, the power driver will be simply the function of four variables:

$$\text{Power Driver} = f\left[P_{cmd}, P_{ctl}, P_{comm}, P_{int}, \alpha\right]$$

The methodology to measure the level of performance will be discussed in Chapter IV, "Test and Evaluation" section. It is obvious, however, that, if every component is well organized with a ideal capability excluding human factors such as motivation and distortion of information by human, the value of Power Driver will be 1, and it will drive 100% of fire distribution to the target. This is represented by the formula such as

$$\text{Operational Force Power} = f\left[\sum_{i=1}^{n} P_{(i)}\right] \cdot F$$

where

F is the fixed force power available for commitment to an operation.

Adapting the characteristics of the f function, if any one of those components in C^3I has a critical poor performance, regardless of the other's capability, the total power of the force will decrease by the critical weak component's ratio. On the other hand, any increase in each component will increase the total power by the multiple ratio, too.

So it is not true that the force must attack only the enemy's fire weapons to remove his response capability to carry out war. To attack those C^3I components is another point of fire distribution. These attack techniques are collectively called C^3 CounterMeasures or C^3CM.

2. C^3 Countermeasures

Assume that both Blue and Red forces have the same fire assets, then the balance of power depends on the their C^3I capability. If the forces have a C^3CM capability to degrade the Red Forces' C^3I, then the total Red Forces power in battlefield will be degraded and the total Red Forces power will be represented by

$$\text{Red Forces' Operational Battle Power} = \left[1 - g(C^3CM)\right] \cdot F_r$$

where

Both Blue and Red Forces C^3I capability are the same

F_r is the Red Forces' fixed force power for operations.

g is the function of C^3CM performance

Countermeasures are comprised of one or more of the disciplines or techniques employed by themselves or, more commonly, in some combination to deny information to, influence, degrade, or destroy adversary C^3 capabilities and to protect friendly C^3 against such actions. The concept of C^3CM can be broken down into two related concepts, degradation of enemy C^3 and protection of friendly C^3 from enemy degradation: *Counter–C^3 and Protect* C^3. These use the techniques of jamming, military deception, OPSEC, and physical destruction [Ref. 37:p. 18].

- Jamming – This technique involves both acoustic and electronic jamming. Acoustic jamming is the deliberate radiation or reradiating of mechanical or electroacoustic signals with the objectives of obliterating or obscuring signals that the enemy is attempting to receive and of deterring enemy weapon systems. Electronic jamming is the deliberate radiation, reradiation, alteration, or reflection of electromagnetic energy for the purpose of disrupting enemy use of electronic device, equipment or C^3I system.

- Military Deception – This technique involves actions executed to mislead foreign decision makers, causing them to derive and accept desired appreciations of military capabilities, intentions, operations, or other activities that evoke foreign actions that contribute to the originator's objectives.

- OPSEC – Operations security is the process of denying adversaries information about friendly capabilities and intentions by identifying, controlling, and protecting indicators associated with planning and conducting military operations and other activities.

- Physical Destruction – Although physical destruction is an option, it must consider the rules of engagement, expendable nature of lethal weapons, and their requirement for extremely accurate target location information, which may make non–lethal options (e.g., jamming and deception) more effective.

But thanks to the current state of the art, there is another possible technique to degrade the enemy's C^3I capability. It is to insert the computer virus into the defense computer network in peace time as well as in war time so that it works during the initial engagement of battle in order to disrupt the early warning system.

III. THE FRAMEWORK OF C^3I SYSTEM

A. OVERVIEW

In order to develop a system, the first step is to define the concept. But the various terms of C^2, C^3, C^3I, C^4, and C^4I^2 cause confusion. In Chapter I, however, battle management is defined as the process of managing a battle with the intent of destroying an enemy's weapon system. This is done by battle managers through the C^3 system. In this thesis, the various terms of command and control will be represented by C^3. When a C^3 system is developed, the developer has to approach it in two ways. One is the invisible form of C^3 (C^3 process), the other is visible form of C^3 (C^3 system). In the remaining part of this thesis, the term of C^3 will be used as the process of command and control, and the *C^3 SYSTEM* will refer to the tangible form of command and control. Basically, the concept of C^3 will be defined as the process, through which commander controls his resources and ensures unity of effort to respond to its challenge, which is conducted by C^3 system.

The purpose of C^3 process and C^3 system is to assist the commander in accomplishing his mission. So the development of C^3 system highly depends on the commander. The problem solving way of a commander is called the command structure, and control is a support mechanism for command. The way to assist the commander through C^3 system is to reduce uncertainty so that the commander makes a sound decision. This is the capability of intelligence analysis of C^3 system. But the decision must be made in time, faster than the enemy's action. This requires fast and large volumes of communications traffic. So for the purpose of C^3 system, it requires a well organized command structure, control mechanism, intelligence capability, and communication link.

C^3 system is a means of battle management which is an overall term for the commander's activities to reach his goal on the battlefield. A battle management system consists of the battlefield to be managed, sensors to monitor the battlefield, weapons to change the battlefield to the desired state, a battle manager who manages the battle, and the C^3 system which is used by the battle manger.

The boundary of the C^3 system is limited to the command and control functional system and its subordinate organizations. Figure 3.1 depicts a battle management system configuration. The C^3 system is located between sensor and weapon. The boundary of the C^3 system will include both the command and control process and organization. And, it depends on the system context which affects the transformation function of command and control and on the various types of organization.

The function of the sensor is to monitor the change of states and the function of the weapon is to respond to the change in order to make the battlefield stay at the desired state. The function of the C^3 system will be the transformation of threat (change of state) into peace (desired state). This transformation function will be conducted in accordance with its force organization.

The battle manager will be the commander of the force, or staff of the commander who has a limited command authority. They are the control organ of the C^3 system. In Chapter II, they are considered as decision makers. So, if they are included in the C^3 system, the C^3 system will be the decision making system, otherwise the C^3 system will be the decision support system. But, it is very difficult to develop a C^3 system using the model of decision making system which includes the commander's role within the system itself. Also, the characteristics of the commander vary as much as the characteristics of human problem solving vary. So, if the system is developed like that, it will create a commander–dependent C^3

system. So the battle manager should have a standard model. It is the C^2 organization model or decision maker model which is the distributed decision making model in the hierarchical military organization.

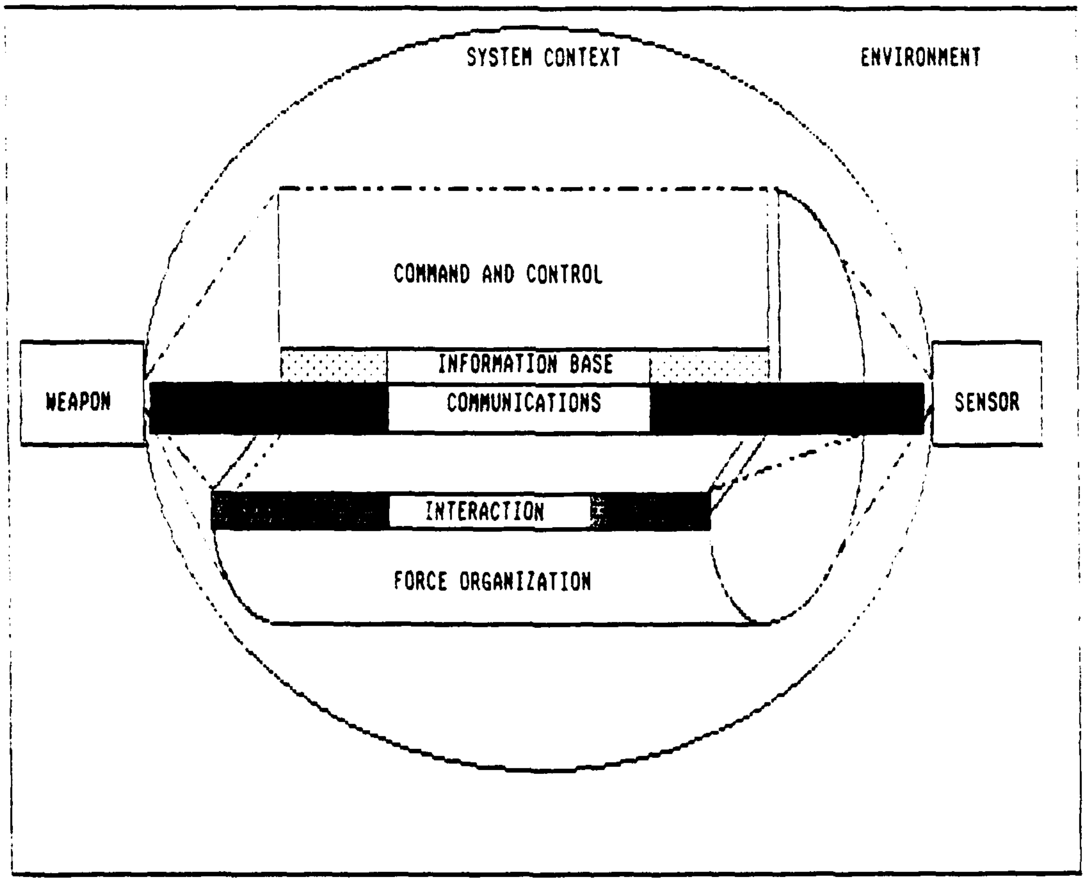


Figure 3.1 BMS Configuration

In developing C^3 system, the development will be divided into three fundamental area. They are the standard, distributed, hierarchical decision making model, the force organizing model, and the C^3 functional transformation model. But, all of these three development approaches will have a certain consistency. It is the time–uncertainty distribution under its system context.

The information base and communications components will be used continuously to perform those functions by the subsystems. So the information base must be developed properly to support each function corresponding to each subsystem. The main components of the information base are the data base, the model base, and the rule or knowledge base. The communications components will be the voice communications system, the common user multichannel system, and the high volume digital data communications system.

Figure 3.1 can be viewed in three directions: the physical layers of a C^3 system from the side direction, the C^2 process with time and information distribution from the front direction, and the operation of the C^3 system from the rotation direction.

The physical layers of a C^3 system may be represented by communications core layer, information base layer surrounding the communications path, C^2 transformation function layer, and C^3 system structure layer corresponding to the force organization level (Figure 3.1.1).

However, the process of C^3 system can be viewed in terms of C^2 process time line and information distribution over the sequential C^2 process time line. As shown in Figure 3.1, the C^2 process is to transform a status information from the sensor into the command or control information for the weapons. This process consists of many sequential or parallel substeps and links between those substeps.

As the information is transformed, each level of organization has a distributed information at a time. The major steps of the sequential transformation process consists of observation, decision, and execution. Figure 3.1.2 depicts this information transformation function.

The operation of a C^3 system is conducted by the interaction between the C^3 system and the users, or man–machine interaction. The definition of the C^3 system includes the force organization structure (e.g., the chain of command) as well as the C^3 information system network. Figure 3.1.3 depicts the interactions for the C^3 system operation. The type of interaction for C^3 system operation has three classes. The first is the tactical interaction between or among the elements of the force organization such as peoples (e.g., operators, staffs, and commanders) in the same level or different level using the C^3 system, weapons, or units. This can be conducted by identification, transportation. communication, and infliction. The second class is the technological interactions between or among the C^3 system network within the network or outside the network. This is possible through the compatibility, standardization of data and procedures. The last is the man–machine interaction between the C^3 information system terminal and the operators. The C^3 system operation is initated by the sensor management for data collection and terminated by the weapon enagement control for fire distribution.

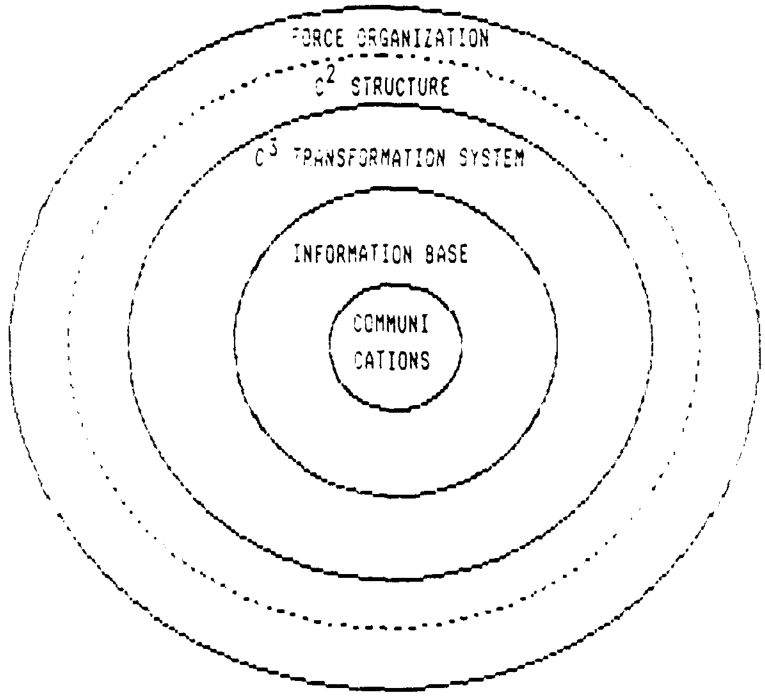


Figure 3.1.1 Physical Layers of a C^3 System

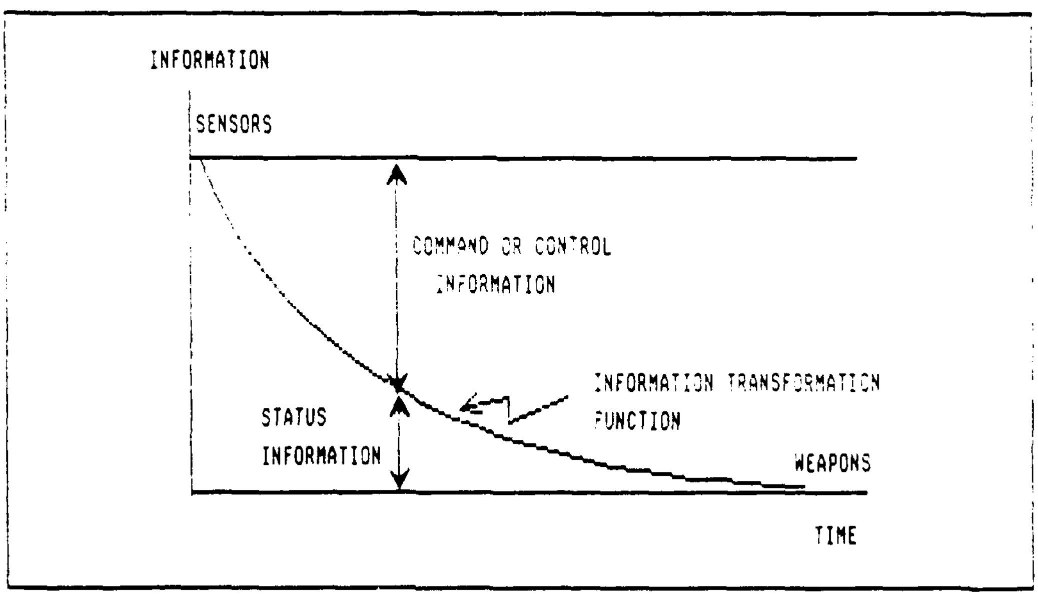


Figure 3.1.2 C^3 Transformation Function

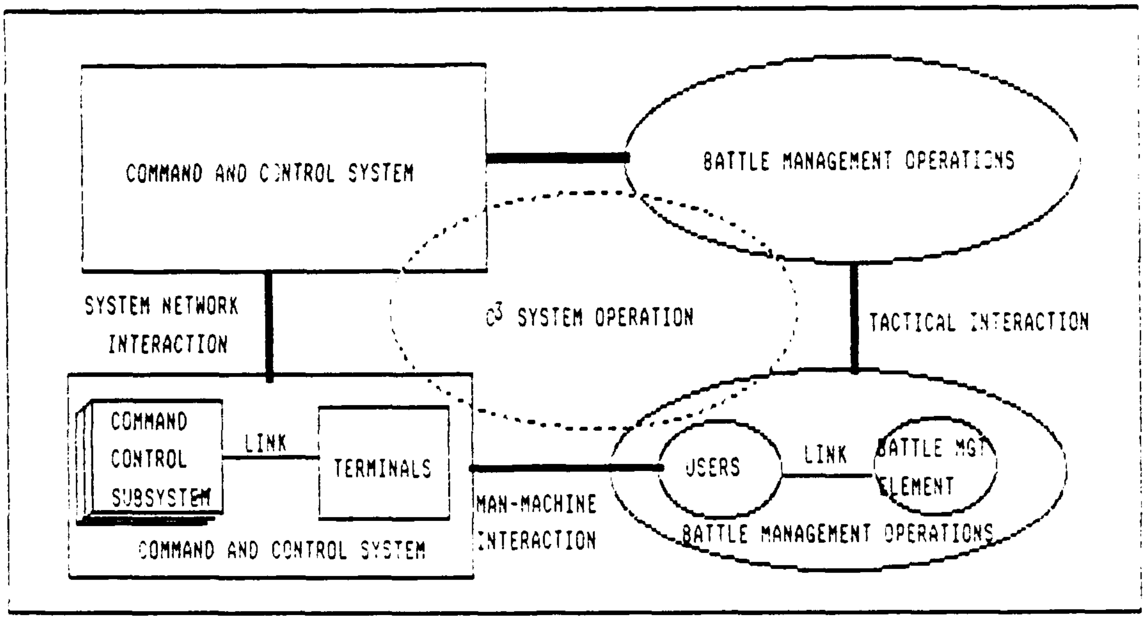


Figure 3.1.3 Interactions for C^3 System Operation

B. THE PERSPECTIVES OF SYSTEM CONTEXT

1. System Operations Environment

The battlefield is filled with uncertainty, stochastic combat outcomes, and the other manifold factors such as human motivation, high probability of communications link failure, and failure of control over the subordinate force. The system context is the outcome of those factor's analyses. The C^3 system must be designed to meet the requirements of the system context. Figure 3.2 is depicted to be used as a reference for C^3 system development expanding Figure 3.1. As shown in the figure, the environment has three attributes: uncertainty, time, and threat. It will determine the system context which is placed in three dimensions of attributes.

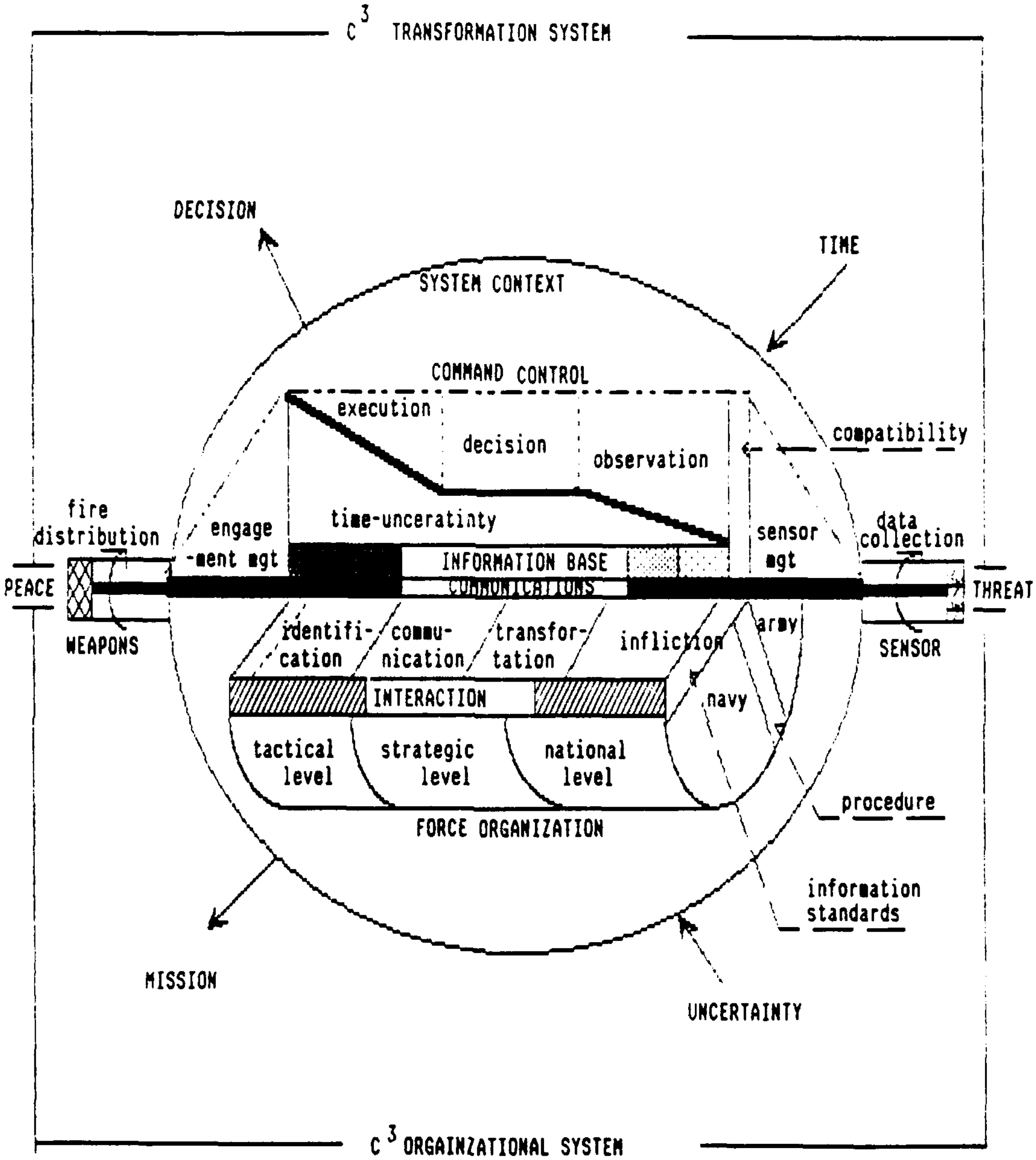


Figure 3.2 The Integrated Framework of C^3 System

Given an amount of time and uncertainty to response to the threat, the C^3 transformation system will make various decisions: informational decisions, organizational decisions, and operational decisions, and this decisions will be transformed via a mission to its subordinate organization. Then, the subordinate organizations will require the time–uncertainty product to carry out the mission in turn. In terms of requirements, if the force is well organized with its subordinate force structure, doctrines, sensor, and weapons in order to carry out the mission effectively, the requirements of time and certainty at that level will be less than that of the opposite case. In other words, the force must be organized corresponding to its operational condition and the expected missions. The C^3 organizational system determines the requirements of time–uncertainty product at that level.

Once the requirements are determined, the C^3 transformation system should have a capability to meet this requirements. A good C^3 transformation system will reduce the uncertainty more than the poor C^3 transformation system does in a given time and support a better decision.

The battle manager of the battle management system is, however, a separate area in terms of a C^3 system, even though it is the central element of a C^2 organization. It is not possible to develop a battle manager except for a computer algorithm in a limited area, because it is highly dependent on the ability of the commander to use the battle management system. An alternative way is to train the commander as the good battle manager. But, in this thesis, the way of making a good battle manger will be excluded because it is a separate part of C^3 system in terms of system development.

2. Decision Types

In a tactical situation each commander is presented with a view of the "state of the world" which he knows can be inaccurate and not necessarily very timely. Nonetheless, on the basis of this incomplete information, each commander must make decisions consistent with the constraints imposed by the preplanned actions. Typical decisions involve [Ref. 17:pp. 22–23]:

- *Control of surveillance resources* (e.g., turn on a radar, launch a reconnaissance aircraft, etc.) to gather more information or clarify ambiguous information;
- *Control of electromagnetic radiation* (e.g., communicate or not, jamming strategies, etc.);
- *Control of resources* (e.g., relative positions of ships, aircraft, tanks, troops, etc., and control of their movement);
- *Assignment of weapons to targets* (e.g., sortie planning by deciding what aircraft, from what bases should be armed, with what weapons to attack what targets or other objects of military value);
- *Weapons control.*

These decisions are always made by human commanders and partially by computer algorithms. Some of the decisions are strategic in nature, i.e., they are the outcome of extensive preparation and planning. In a system theoretic context, the strategic decisions and planning are roughly equivalent to the establishment of desired open loop controls and trajectories; and one can argue that such strategic or command decisions are the outcome of a strategic or dynamic deterministic optimization problem. In this phase, intelligence information is crucial. In the planning phase, many details are not taken into account. Uncertainty is usually handled by planning in detail alternate options; specific and unambiguous objectives; and directives are command for execution and implementation by the

appropriate commanders. The command function effectively specifies the reference trajectories in time and space for the mission to be performed. [Ref. 17:p. 23]

C. THE PERSPECTIVES OF C^3 ORGANIZATION

The C^3 organizational system will consist of force organization and doctrines. The force organization is classified by the level of organization, type of forces. The systemic organizational model, which is presented in Chapter II, states that the function of organization is to produce information and control the organization itself by its control and operational system. The forces must be well organized for the effective information handling and environment control. Related to a command and control organization, there are three primary organization models which must be reviewed to be applied to C^3 organization design: the rational system model, the *natural system model, and the open system model* [Ref. 38:p.3].

1. Overview of Organization Model

The rational system model emphasizes the role of the organization in attaining specific, predetermined goals with a maximum of efficiency. The classical/traditional theory (Mooney, Reiley, 1939; Gulick, Urwick, 1937) of the rational system model stresses the hierarchical structure, unity of command, span of command, management by exception, distribution and grouping of specialized subunits, and line/staff distinctions. But the formal organization model ignores the informal, or behavioral structure of the organization. Also it is impossible for the behavior of a single, isolated individual to reach any high degree of rationality. To compensate the behavioral aspects of organization, the natural system model emphasizes the importance of the behavioral structure rather than formal structure of the organization. [Ref. 38:pp. 4–9]

The informal factors underscore the difficulties in effectively matching information support systems to the partially structured decision tasks faced by battle staffs during combat. So they introduced "structured" versus "semi–structured" versus "unstructured", instead of "rational" versus "non–rational" (Keen, Scott Morton, 1978). A perspective on organizations emphasizes the influence of the organization's environment on its internal structure and operations. In military organizations, it is a critical because the implications of command and control process is to control the environment toward the organization's desired state. However, the rational system models are internally oriented and do not account for the larger environmental contexts within which the organization exists. So the open system model states that organization can be seen as imbedded within larger organizations (Boulding, 1956). [Ref. 38:pp. 12–14]

The open system model emphasizes the process of organizing, rather than one structure of the organization. The process of organizing serves to reduce the level of equivocality or uncertainty in the interaction with the environment. That is, organizational structures and operating rules will evolve to reduce the equivocality of the information received from its environment. The purpose of such structures and rules is to establish a workable level of certainty for the organizational decision process. [Ref. 38:pp. 14–15] In other words, the organization forms the command structure, which generates the chain of command in military organization. According to Weick (Weick, 1969), this reduction of information uncertainty occurs in three stages: [Ref. 38:p. 15]

- Enactment – the information collectors of the organization "creates" a perception of the environment which contains a certain degree of equivocality.

- Selection – the organization applies rules or routines to this information in an effort to structure it in relevant terms: the greater the equivocality, the fewer number of rules which can meaningfully applied.
- Retention – the organization determines what information is to be retained (and acted upon) and what information is to be discarded (i.e., the organization picks and choose which inputs to react to.).

The centralization of command and decentralization of control (two doctrinal principles of U.S. military forces) are direct interpretations of the rational model and in particular, reflect Simon's concept of bounded rationality, and a third doctrinal principle, coordination of effort, reflects the basic notions found in Max Wever's discussion of bureaucracy [Ref. 38:p. 5, translated writings of Wever, 1947]. Taylor's concept of scientific management is manifested in two primary ways: the definition of specialized positions and the design of specialized information support systems. Thus the rational system model is seen to closely resemble the ideal or prescriptive form of command and control. [Ref. 38:p. 6] In addition, the review of all those models suggests that, much of the open system model of organization applies directly to command and control systems. Certainly, command structures can be viewed as imbedded, hierarchical systems: theater commands can be broken down into component service commands, component service commands into geographic or specialized subordinate commands, and so forth. At each level there exists an organizational entity with defined goals and procedures. [Ref. 38:p. 16]

2. Internal Structure of Organization

The scientific management theory of the rational system model states that positions and responsibilities would be redesigned to match human capabilities while personnel would be trained to perform at maximum proficiency [Ref. 38:p. 5]. Also commanders and battle staffs are required to develop informal operating procedures and organizational structures. Informal liaisons and other ad hoc

relationships evolve to exchange critical information [Ref. 38:p. 8]. To design the position and responsibility and to develop the organization structure, the internal parts of organization must be analyzed. Different parts of the organization play different roles in accomplishment of work and of these forms of coordination. Henry Mintzberg [Ref. 39:p. 278], states that there are six basic parts of an organization (Figure 3.3).

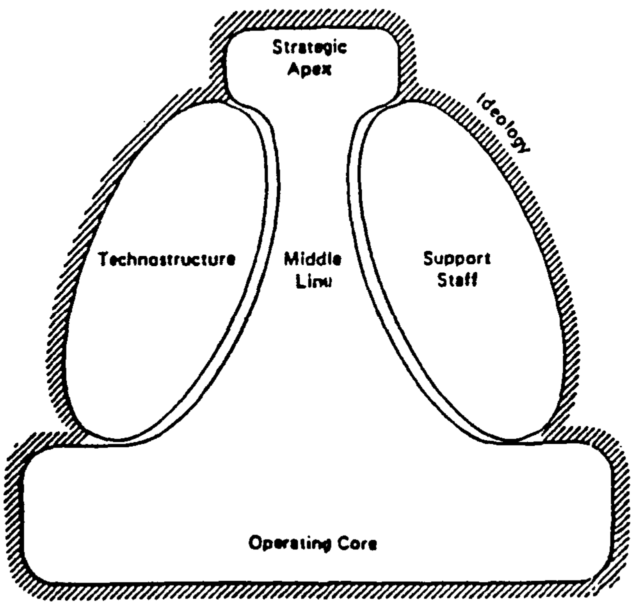


Figure 3.3 The Six Basic Parts of an Organization

The operating core is where the basic work of producing the organization's products and services gets done.

The strategic apex is the home of top management, where the organization is managed from a general perspective.

The middle line comprises all those managers who stand in direct line relationship between the strategic apex and operating core.

The technostructure includes the staff analysts who design the the systems by which work processes and outputs of others in the organization are formally designed and controlled.

The support staff comprises all those specialists who provide support to the organization outside of its operating workflow.

The ideology is a kind of halo of beliefs and traditions that surrounds the whole organization.

Mintzberg points out two major points regarding this view of the organization. First, there is a distinction between "line" and "staff", which is a valid distinction in certain types of structure. Second, there are two kinds of staffs. The support staffs provide just special services while the techno structure "advises" in the usual sense normally associated with a staff.

3. Command and Control Structure

In the open system model of an organization, the military organization was described by an embedded system within the larger organization. This embedded system model is formulized as the divisionalized form of an organization in Mintzberg's work [Ref. 39:p. 301], Figure 3.4 is the divisionalized form by Mintzberg.

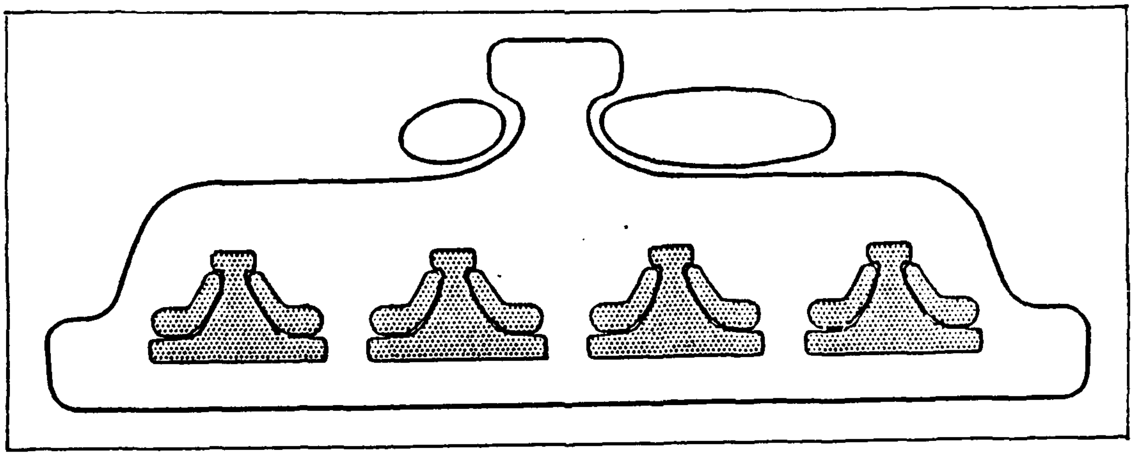


Figure 3.4 The Divisionalized Form

The command and control structure, which is classified with two major types: centralized and decentralized, describes the delegation of formal power down the the hierarchy of authority. In terms of military command and control, the formal power is the decision making power. So with the sharing of the decision making power, if all the power rests at a single point in the organization, the structure is called centralized; to the extent that the power is dispersed among many individuals, the structure is called relatively decentralized. [Ref. 39:p. 289]

Centralization has one great advantage in the organization. By keeping all the power in one place, it ensures the very tightest form of coordination. All the decisions are made in one head, and then implemented through direct supervision. But one brain is often not enough. It cannot understand all that must be known. However decentralization allows the organization to respond quickly to local conditions in many different places, and it can serve as a stimulus for motivation [Ref. 39:p. 290]. By mixing the advantages of two parameters of command and control types, an organization can be designed for the optimal performance.

With the direction of dispersing the power, there are vertical decentralization and horizontal decentralization [Ref. 39:p. 290].

- Vertical decentralization – the delegation of formal power down the hierarchy to line managers
- Horizontal Decentralization – the extent to which formal or informal power is dispersed out of the line hierarchy to non–managers (operators, analysts, and support staffers).

When organizations decentralize extensively, they do so selectively, delegating power for each decision process to that level in the line hierarchy where the necessary information can best be accumulated. Power is dispersed to different

places for different decision processes. The power over only one or a few kinds of decisions is dispersed to the same place in the organization. It is called selective decentralization. On the other hand, the dispersal of power for many kinds of decisions to the same place is called the parallel decentralization. [Ref. 39:p. 290]

With two distinction parameters of decentralization (vertical/horizontal and selective/parallel), there must be a different form and a different degree of decentralization. Then centralization can be a type of decentralization with high degree of power ratio over one place. Among the six types of decentralization (Type I – Type VI), Type I is the centralization form of an organization [Ref. 39:p. 292].

For the military decision making organizations, which is considered as the distributed decision making based on centralized planning and decentralized execution [Ref. 11:p. 127], the command and control structure will be represented by Type I centralization form embedded in the larger organization. Figure 3.5 is depicted for the distributed decision making organization form. The inflated size of the shaded parts indicates their special power in decision making, not their size.

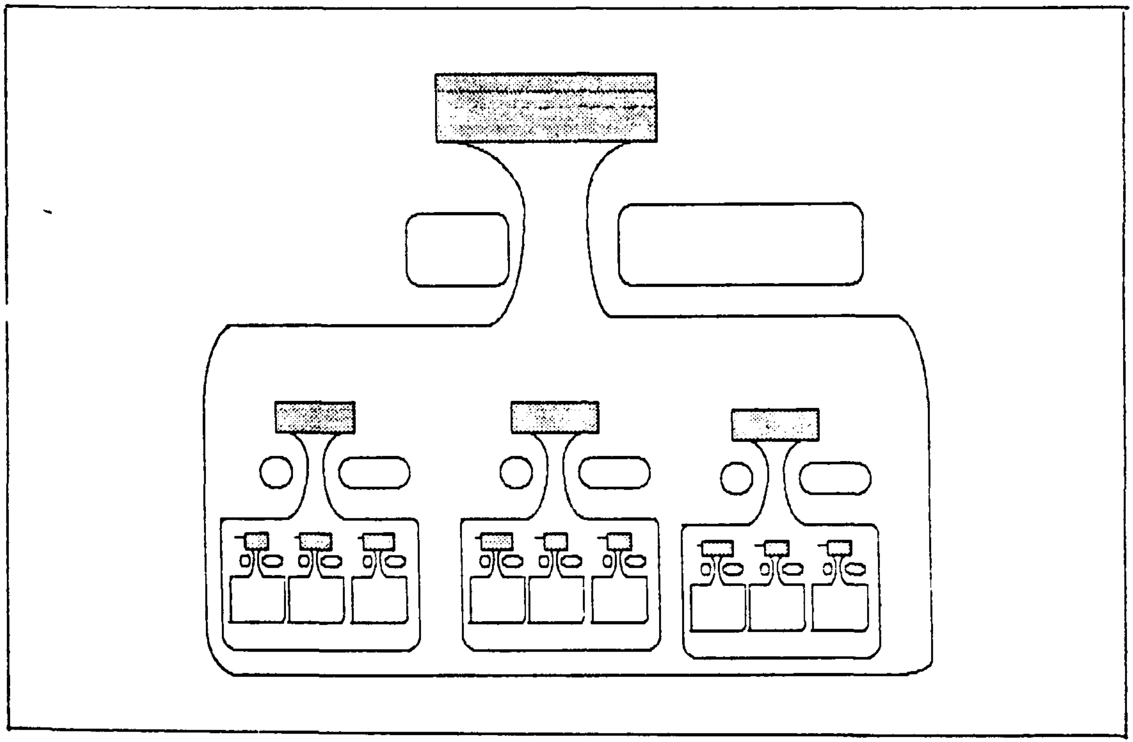


Figure 3.5 Distributed Decision Making Organization

4. Doctrines and Policy

The rational system model of an organization states that personnel must be trained for the maximum proficiency of the organization objectives. The national security objectives are supported by the force's strategy in strategic level and tactics in operational level. In business management, the strategy is defined by Andrews that "strategy is a pattern of decisions a company that determines and reveals its objectives, purposes or goals, produces the principle policies and plans for achieving those goals..." [Ref. 40:p. 59, quoted from Andrew, 1980]. The concept of strategy in military field is defined that " strategy is the comprehensive direction of power, and tactics is the immediate application of power" [Ref. 40:p. 63, quoted from

Rosinsky, 1977]. Also Clausewitz says that the aim of strategy is the destruction of the enemy forces on the battlefield. Adapting these definition, Liddel–Hart definition of the strategy, "the art of distributing and applying military means to fulfill the ends of policy", is adequate to military term of strategy [Ref. 40:p. 63, quoted from Liddel–Hart, 1968]. The implications of art of distribution and application of military means can be expanded by military analysts in various way. One form of this art is the principles of war.

FM 100–5 says that there are nine principles of war such as objective, offensive, mass, economy of force, maneuver, unity of command, security, surprise, and simplicity.

The meaning of objective is that the direction must have the clearly defined, decisive, and attainable objective. Offensive is to seize, retain, and exploit the initiative. Mass is to concentrate combat power at the decisive place and time. Economy of force is to allocate minimum essential combat power to secondary efforts. Maneuver is to place the enemy in a position of disadvantage through the flexible applications of combat power. Unity of command is to ensure the unity of effort under one responsible commander. Security is not to permit the enemy to acquire an unexpected advantage. Surprise is to strike the enemy at a time or place, or in a manner, for which he is unprepared. Simplicity is to prepare clear, uncomplicated plans and clear, concise orders to ensure successful operations through understanding. [Ref. 41]

But, the point of views between Western military scientists, Soviet military scientists and others are little different. The different viewpoints are shown in Figure 3.6 [Ref. 42:p. 4].

UNITED STATES	*GREAT BRITAIN AUSTRALIA*	*SOVIET UNION* "PRINCIPLES OF MILITARY ART"	*FRANCE*	*PEOPLE'S REPUBLIC OF CHINA*
OBJECTIVE	SELECTION & MAINTENANCE OF AIM			SELECTION & MAINTENANCE OF AIM
OFFENSIVE	OFFENSIVE ACTION			OFFENSIVE ACTION
MASS	CONCENTRATION OF FORCE	MASSING & CORRELATION OF FORCES	CONCENTRATION OF EFFORT	CONCENTRATION OF FORCE
ECONOMY OF FORCE	ECONOMY OF FORCE	ECONOMY/ SUFFICIENCY OF FORCE		
MANEUVER	FLEXIBILITY	INITIATIVE		INITIATIVE & FLEXIBILITY
UNITY OF COMMAND	COOPERATION			COORDINATION
SECURITY	SECURITY			SECURITY
SURPRISE	SURPRISE	SURPRISE	SURPRISE	SURPRISE
SIMPLICITY				
TIMING & TEMPO LOGISTICS COHESION	MAINTENANCE OF MORALE	MOBILITY & TEMPO SIMULTANEOUS ATTACK ON ALL LEVELS PRESERVATION OF COMBAT EFFECTIVENESS INTERWORKING & COORDINATION	LIBERTY OF ACTION	MORALE MOBILITY POLITICAL MOBILIZATION FREEDOM OF ACTION

Figure 3.6 Principles of War

in the real battlefield, these principles will be inserted into each tactical operations corresponding to the battle manager's way of doing. This way of doing of each battle managers in a force command must be standardized toward the force's objective. Otherwise, the power of forces will be scattered. So the objective must be in mind always, and the forces must have a standard operating procedures (SOP). By training the battle managers through the SOP, they can have a consistent way of doing in the real battlefield over the mission. In the perspective of command and control, this resembles the coordinating work or interaction among the subparts of an organization. A role of doctrines is to train the individuals toward the consistent way of problem solving for organization's own benefit. As a parameter in the design of individual positions, indoctrination resembles training in many ways. It too takes place largely outside the job—often before it begins—and is also designed for the internalization of standards.But the standards differ and are unique to each organization. Thus indoctrination must take place within its own walls under full control of its own personnel [Ref. 39:p. 282].

D. THE PERSPECTIVES OF INTERACTION

The techniques of interaction such as compatibility, information standards, and procedures. Those of interaction will be the classification of identification, communications, transportation, and infliction.

For the coordinating works, Mintzberg developed "the six basic mechanisms of coordination" (Figure 3.7). Six mechanisms of coordination seem to describe the fundamental ways in which organizations coordinate their work. Two are ad hoc in nature; the other four involve various forms of standardization. [Ref. 39:pp. 278–280]

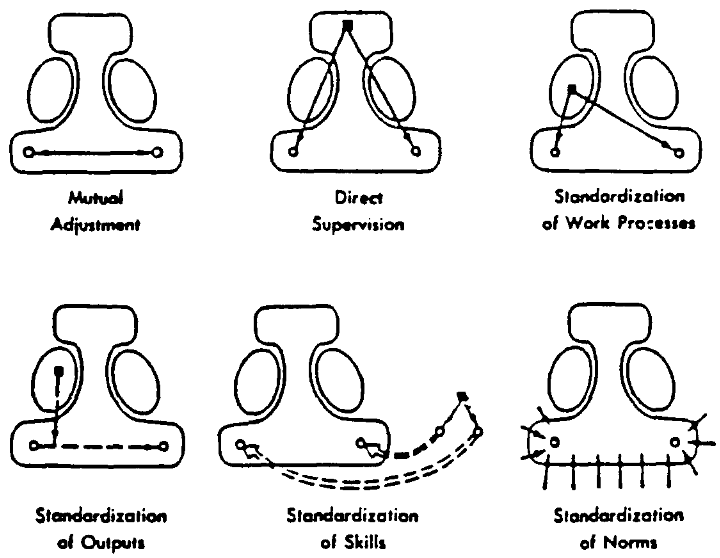


Figure 3.7 Six Basic Coordinate Mechanisms

Mutual adjustment achieves coordination of work by the simple process of informal coordination. The people who do the work interact with one another to coordinate, much as two canoeists in the rapids adjust to one another's action. Figure 3.7a shows mutual adjustment in terms of an arrow between two operators.

Direct supervision in which one person coordinates by giving orders to others, tends to come into play after a certain number of people must work together. Thus, 15 people in a war canoe cannot coordinate by mutual adjustment; they need a leader who, by a virtue of his instructions, coordinates their work, much as a football team requires a quarterback to call the plays. Figure 3.7b shows the leader as a manager with his instructions as arrows to the operators.

Standardization of work processes means the specification– that is, the programming–of the content of the work directly, the procedures to be followed, as in the case the assembly instructions that come with many children's toys. As shown in Figure 3.7c, it is typically the job of the analyst to so program the work of different people in order to coordinate it tight.

Standardization of outputs means the specification not of what is to be done but of its results. In that way, the interfaces between jobs is predetermined. Such standards generally emanate from the analyst, as shown in Figure 3.6d.

Standardization of skills, as well as knowledge. is another, though looser way to achieve coordination. Here it is the worker rather than the work or the outputs that is standardized. He or she is taught a body of knowledge and a set of skills which are subsequently applied to the work. Such standardization typically takes place outside the organization–for example in a professional school of a university before the worker takes his or her first job–indicated in Figure 3.7e. In effect, the standards do not come from the analysts; they are internalized by the operator as inputs to the job he takes. Coordination is then achieved by virtue of various operator's having learned what to expect of each other. When an anesthetist and a surgeon meet in the operating room to remove an appendix, they need hardly communicate (that is, use mutual adjustment, let alone direct supervision); each knows exactly what the other will do and can coordinate accordingly.

Standardization of norms means that the workers share a common set of beliefs and can achieve coordination based on it, as implied in Figure 3.7f. For example, every member of a religious order shares a belief in the importance of attracting convert, then all will work together to achieve this aim.

Chapter II introduced that the technologies of interoperabilit consists of compatibility, standardization, and procedure. In the section above, also, the procedure is a mean of interaction among the subparts in an organization. But the organization refers to the overall embedded organization which specifies the distributed decision making and execution organization. If the six basic mechanisms of coordination are expanded out of the overall organization, however, interactions among each subparts of all component organizations can be formulized over the distributed decision making model which is a embedded organization.

In Chapter II, the open system model stated that the interaction can be implemented through the four fundamental types: communication, transportation, identification, and infliction. Each resource involved in a conflict in each component level of a lager organization, as a minimum, must be capable of communications, while the capability for any one or more of the remaining types of interactions depends on the specialty of the resource. For example, weapon resources must be

capable of infliction, sensor resources must be capable of identification, and logistics resources must be capable of transportation [Ref. 36:p. 16.2.3].

In terms of command and control, however, the critical resources in the environment are people and information. The interaction among people in the organization is possible through the expansion of the six basic coordination mechanisms. On the other hand, information systems, encompassing the processors and interconnecting networks, provide the interaction between people and information, and among the information in different places [Ref. 43:p. 12.2]. To provide significant interoperability, in the C^3 mainframe environment, there must be extensive communications support. A mainframe user is now someone with an intelligent terminal, workstations or user on another system. These users need the flexibility to transparently access the data processing resources in their organization [Ref. 43:p. 12.2].

The most information that a commander needs is the location, velocity, and identity of his own, enemy's and neutral objects [Ref. 17:p. 22]. So the standardization of information provides the easiness of access. The methodology of accessing the information will be the OSI seven layer model of information system and ISDN (Integrated Services Digital Network) technology in communications networking. The application designer has a major responsibility in achieving interoperability.

E. THE PERSPECTIVES OF C^3 TRANSFORMATION SYSTEM

In the previous section, various organization models introduced the formal structure of power delegation. In the real world, however, the formal structure is not good enough for tactical information exchange and technical weapon (or force)

control. The sharing of decision making power over the formal organizational position must be augmented by the sharing of decision making functions over a virtual networking node. In other words, C^3 system is built by a virtual functional system under the main frame of the formal organizational architecture.

The C^3 functional transformation system is divided into three subsystems which will perform the C^3 process. The functions of these subsystems are identical to information management, decision management, and executive management functions of Thornton's conceptual architecture of the C^2 process. The input to the observation subsystem is the data from the sensor, and the output is the situation assessment. The data will be processed through various steps such as aggregation, filtration, correlation, analysis, and dissemination. This assessment is then transformed to a decision through the decision subsystem which develops a course of action, estimates the enemy's response, and evaluates the course of action with comparison. Finally, this decision will be transformed into implementation form such as fire distribution in execution subsystem through the steps of development of plan, preparation of directives and reports, and issuance of plans, orders, and reports.[Ref. 25:p. 141]

1. Information and Control Applications Model

The implemented form of the conceptual architecture is the applications information system. The applications model of information system determines the system capability to support the battle managers including both commanders and staffs. Current research for modeling of C^3 functional system intends to develop C^2 process model, command and headquarters model, combat and conflict models, surveillance and fusion models, communications model, EW and counter–C^3

models, and information and control model. The typical elements of C^3 functional models are shown in Table 3.1 [Ref. 44:p. 29]

For the C^2 process model, general C^3 paradigms are discussed in Chapter II. Sample dynamic theory has been approached by many researchers. The representative dynamic models are: [Ref. 44:p. 32]

- Classical state variable models
  - Thermodynamic (Lawson)
  - Markov models (rubin, Mayk)
- Statistical mechanics models (Ingber)
- Possibilistic models (Zadeh, Goodman)
- Catastrophe and chaos (Dockery, Woodcock)
- Adaptive control (Strack)

Table 3.1 C^3 Functional Models

FUNCTIONAL MODELS	TYPICAL ELEMENTS
• PROCESS MODELS	SYSTEM DYNAMICS
• COMMAND AND HEADQUARTERS MODEL	DECISION-MAKING MODEL, STAFF ELEMENTS, DATA FUSION
• COMBAT AND CONFLICT MODEL	PHYSICAL RED-BLUE ENGAGEMENT MODEL
• SURVEILLANCE AND FUSION MODEL	CLASSICAL RADAR, IR, SONAR, PHOTO (BOTH FIXED, MOVING), INTERNETTING, PRELIMINARY FUSION. (RED, BLUE, ENVIRONMENT) STATUS REPORTING, INTELLIGENCE, I&W, WEATHER FORECASTING
• COMMUNICATIONS MODEL	CAPACITY, CONNECTIVITY, S/N, ERROR RATE, SECURITY, AJ CAPABILITY
• EW AND COUNTER-C^3I MODEL	DECEPTION, DESTRUCTION, JAMMING EXPLOITATION
• INFORMATION AND CONTROL MODEL	TOPOLOGY, PROCESSING AT VARIOUS NODES, DATA BASE DISTRIBUTION & MANAGEMENT, CONSTRUCTION & DISSEMINATION OF TASKING ORDERS, EAM'S

At their present stage of development it is premature to attempt a comparative analysis of the value of these various models. To make these or other dynamic models useful, three steps are important: [Ref. 44:p. 33]

- Model a reasonably realistic scenario,
- Correlate the results with a simulation, test bed, or actual experience and understand the differences between the results,
- Explain the lessons learned and the significance of the conclusions in terminology that is familiar to a commander.

Command theory is the first functional area of interest. For command and headquarters model, some of the representative elements of a command theory are: [Ref. 44:p. 33]

- What decisions are going to be made at each level in the hierarchy?
- What constraints are there on the commanders option?
- Who does the decision–maker have to interact with?
- What information is required to make each decision?
- What is the decisions time line?
- How timely, accurate and complete must the input information be?
- How should the information be presented to the commander?
- What decision aids are needed?
- Human behavior in a stressed environment.

On the other hand, the elements of headquarters theory consists of

- Information flow patterns,
- Intra–nodal processing, communications and displays,
- Physical topology of headquarters function (distributed, dispersed, centralized),
- Data base structure and maintenance,
- Decision aids, the use of artificial intelligence,
- Survivability of headquarters function.

The headquarters functions are those processes needed to support the commander. Some representative command and headquarters models are: [Ref. 44:pp. 33–34]

- Headquarters effectiveness assessment tool (HEAT)
- Data flow and decision making structure (Petri nets)
- Models of decision makers
- Resource allocation

HEAT treats the C^2 process as an information management system and attempts to measure effectiveness in terms of military mission accomplishment. An application of Petri nets will be discussed in the next chapter.

The next category of models is the combat and conflict models. The representative models are: [Ref. 44:p. 34]

- Lanchester–type equations (deterministic differential equations)
- Stochastic combat models (Markov processes), and
- game theory.

Communications theory is perhaps the most advanced of the various functional areas. The representative elements of communications theory consists of

- User requirements (connectivity, quality, capacity, survivability, environment)
- Generic properties of media and systems
  - Capacity
  - Quality
  - AJ performance
  - LPI performance
  - Survivability
  - Reliability
  - Flexibility
  - Connectivity
  - Time delays

Communications is an area in which the C^3 research community has had a major impact on procurement of DOD systems. As an example, the ARPAnet significantly influenced current DOD communications networks.

For surveillance and fusion theory, the representative elements consists of: [Ref. 44:p. 35]

- Volumes of responsibility and interest
- Generic properties of sensors (e.g., detection, resolution, tracking, capacity, processing capabilities)
- Tasking procedures (e.g., responsibilities, timeliness)
- Information flow from non–organic sensors
- Topology of sensor information flow and fusion

A simple definition of the commander's volume of interest is that space around the commander where actions could have a "real–time" or "near–term" impact on mission accomplishment. Napoleon's volume of interest was probably a circle with a radius of about 100miles. The JCS volume of interest consists of the entire globe. Sensors have continually tried to keep up with this volume of interest in order to reduce the uncertainty about the enemy's intention. This will be discussed in the next chapter in detail.

In terms of command and control, however, these different applications models by different people lack the relationship with the real world. The EW model presented ESM, ECM, and ECCM technologies, but it is still a weapon–oriented system. The essentials of a command and control system are the interaction between or among the people resource and information resource, the response to the enemy commander's potential intentions, and control the forces toward the desired state. So the first mission in command and control studies is to catch the human's intention. But the human intentions will be presented ad hoc by his actions. However, processing the information which is accumulated by observing the pre–actions or diagnosis until the threat takes place, commanders can expect what is happening and what must be done for that. Then he can control his forces based

on this expectation utilizing those applications model above. Thus the key of the models are the information and control model. The elements of information and control model will be

- the uncertainty parameter of battlefield information
- the quality of decisions in response of the information
- the time constraint of control system executing the decisions.

Thus for the information and control system model, the key applications models must be focused on the information base generation model, individual and organizational (or group) decision making model over the chain of command and decision support system corresponding to this model, and the operational (or tactical) control model of the forces in different time and space dimension.

2. Computer–Based Information System

In information system, there are five major types: transaction processing system (TPS), office automation system (OAS), management information system (MIS), decision support system (DSS), and executive support system (ESS) [Ref. 28:pp. 33–36].

> A TPS is a computerized system that performs and records the daily routine transaction necessary to the conduct of the business. TPS serve the operational level of the organization when tasks, resources, and goals at the operational level are predefined and highly structured. The decision has been programmed. TPS are major producers of information for other systems and span the boundary between the organization and its environment.
>
> OAS are computerized devices and systems devoted to document and message processing. Included are word processing, document storage, graphics, reproduction, facsimile transmission, and electronic mail system. OAS support both clerical and managerial functions, spanning the operational and management level.
>
> MIS provide managers with reports and, in some cases, on–line access to the organization's current performance and historical records. MIS primarily serve the functions of planning, controlling, and decision making at the

management level. Generally they condense information obtained from TPS and present it to management in the form of routine summary and exception reports. MIS have highly limited analytical capabilities; they simply use models to present data. Typically, they are oriented almost exclusively to internal, not environmental or external, events.

DSS are devoted to supporting management decisions that are semistructured, unique or rapidly changing, and not easily specified far in advance. DSS have more advanced analytical capabilities that permit the user to employ several different models to analyze information. These systems draw internal information from TPS and MIS, and they often bring in information from external sources. DSS tend to be more interactive, proving users with easy access to data and analytical models through user–friendly computer instructions. An example is a ship tracking system that calculates the ship's optimal speed and direction based on current weather, availability of port facilities, and current location.

ESS are a new category of systems that support decision making by senior management. They serve the strategic level of the organization. ESS address unstructured decisions and involve a generalized computing and communications environment rather than any fixed application or specific capability. ESS are oriented toward external events, although they draw summarized information from internal MIS and DSS. ESS represent less a solution to a specific question than a generalized computing and telecommunications capacity that can be applied to many situations. Compared to DSS, ESS tend to make less use of analytical models; instead, they deliver information to managers on a demand and highly interactive basis in a more open–ended manner.

The roles played by each of the major types of information systems in the organization are shown in Figure 3.8 [Ref. 28:p. 37].

The information system uses the information base as the basic resource of processing. The information base has three types: database, model base, and knowledge base. A database is a set of data organized to serve many applications efficiently by centralizing the data and minimizing redundant data [Ref. 28:p. 242]. The database is the elementary source of information processing. DSS provide models as well as data as a basis for discussing and deciding semistructured and unstructured problems [Ref. 28:p. 495]. The model base has strategic models, tactical models, operational models, and analytic routines [Ref. 28:p. 497, quoted

from Sprague and Carlson, 1982]. The knowledge base have two types of base: rule base and frame base. Rule base is a collection of statements in the form "If x then y," where x represents a condition and y an action. Rule base is used for expert system which is one of application system (rule based expert system). The other type of expert system is a frame based expert system. The frame is a collection of knowledge that describe related concepts by listing each concept's features and showing the relationships to other concepts [Ref. 28:p. 545].

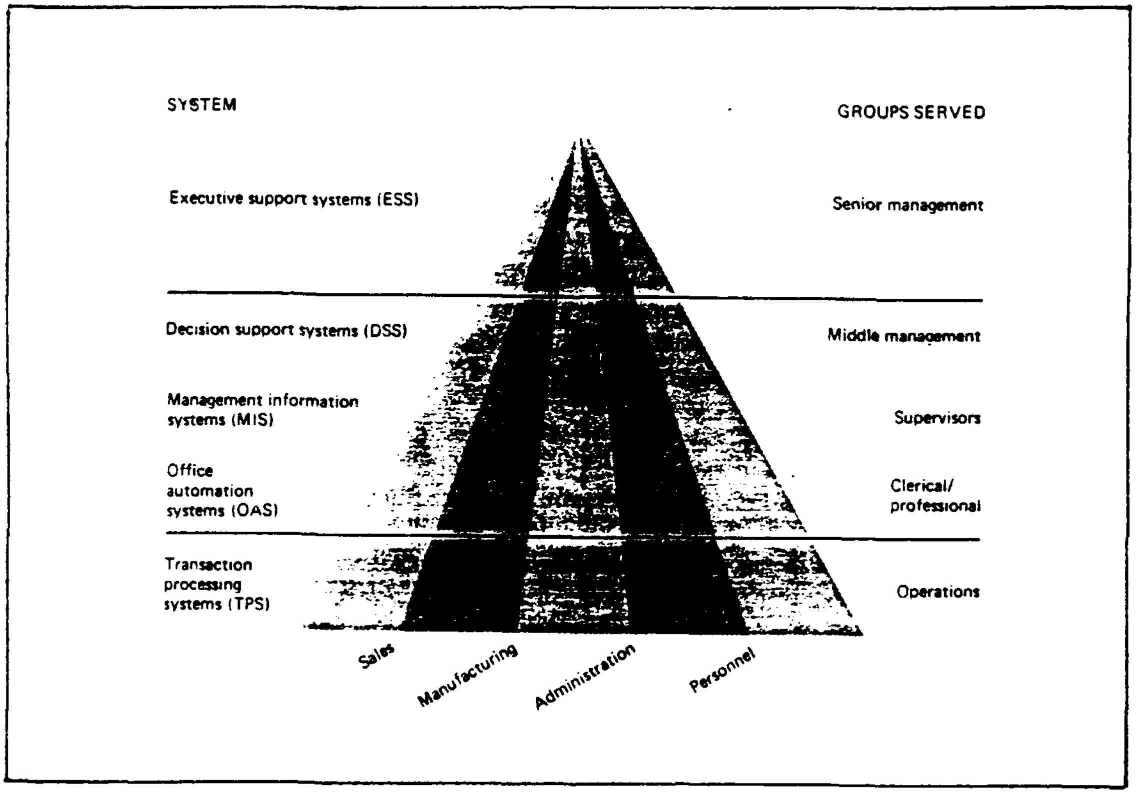


Figure 3.8 Types of Information Processing System

The information base must be built to support interoperability between various decision makings. Thus the information base must have a standardized data structure. For multi–users and multi–services, open system model of organization presented the OSI seven layers for the networking. So that information base must be compatible in other networks as well, an output of one information system must be acceptable as the input of other system. Then the application decision model base must be developed in a consistent way.

In C^3 information systems, commanders will make decisions analyzing information using DSS or decisions will be made partially by expert system or artificial intelligence system following a set of rules or procedures which is the part of knowledge base. The knowledge base of a C^3 system is the entirety of the knowledge, information, or data held in some form in the system's memory, be it maps, books, computer memory, documents, human memory, or switch positions. The assigned mission, rules of engagement, and tables of assigned frequencies are part of knowledge base. [Ref. 45:p. 2]

Data refers to physical observations or measurements of the real world, including such things as charts and histories [Ref. 45:p. 2]. Data is obtained by sensors when events occur externally out of organization and actions are taken internally by individual groups in an organization. This data is processed in observation subsystem. Database in observation subsystem must be developed accessible by other subsystems as well because it is the lately updated information.

Decisions are made when a event requires a response to it. Whether to take a action or not is dependent on the conditions which are the relationships among data elements, and rules which are the basis for many of the decisions that the system makes. In other words, the decisions in decision subsystem is highly

event driven. A event in the battlefield is sensed by different levels of organization at the same time or at least disseminated over the chain of command for the response. Thus the decision making model in decision subsystem must be in distributed network. And the authority and responsibility for the decision making must be shared over the chain of command. It is the distributed decision making system. So the decision support system must support multi–users and multi–services. The process of decision making is that a system selects a model from a model base appropriate for a specific decision, then invokes data from database involved in the decision, finally make a decision based on knowledge. If the knowledge is invoked from knowledge base of computer storage the information system is a stand alone computerized decision making system such as expert system or AI. If the knowledge is inserted by the input of human decision maker through the I/O processes over the information analysis, it will be the decision support system in assistance of decision makers.

3. Transformation Function of Distributed C^3 System

The basic decision making process is represented as consisting of two distinct parts; the evaluation of the current state of the decision maker's environment (situation evaluation), and the selection of responses to minimize the divergence between the observed and goal states (response allocation) [Ref. 46:p. 65]. The first is an information decision and the last is an operational decision. The implication of these decision by decision making system is to transform the situation evaluation into response implementation.

Assuming that the command system is the means for achieving an organization's objectives using assigned effectors and sensor resources to interact with the physical environment, Galley simplified the system as three processes:

perception, command, control process, and signal flows. Figure 3. 9 shows the overall command system [Ref. 47:p. 70, 77].

- perception process– system feedback path
- command process – system feed forward path
- control process – system feed forward path
- signal flow of
    - objectives – goals to be obtained and penalties to be avoided;
    - raw sensory data – sensor resource's response to physical sensation;
    - perception – an intelligible view of the world;
    - method –demanded resource activities, i.e., a required course of action;
    - resource manipulation – orders given to the resources to be translated into physical acts performed on the outside world or other resources.

The role of the perception process is to construct an intelligible view of the world. This entails interpreting and integrating the whole spectrum of sensory data ranging from sonar echoes to political speeches [Ref. 47:pp. 70–71].

The idealized command process must transform objectives and perception of the world into a course of action which will achieve these objectives. Mission planning and mission effectiveness monitoring are two operations mode of command corresponding to the preparatory and execution phase of mission [Ref. 47:p. 71].

The idealized control process must transform the required course of cation, together with a perception of the world, into resource manipulation orders such that actual resource activity complies with the required resource activity. The control process operates in two modes corresponding to the preparatory and execution phases of resource manipulation: resource order generation and compilance monitoring [Ref. 47:p. 71].

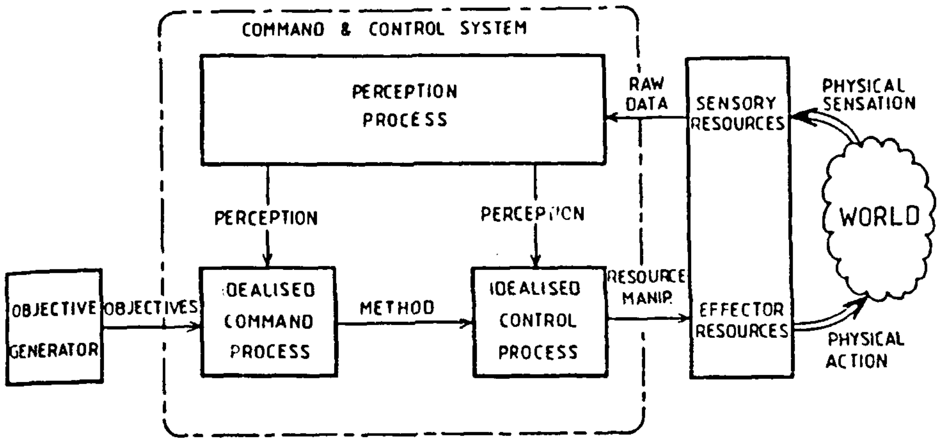


Figure 3.9 The Overall Command System

In general, command systems consists of a distributed, hierarchical organization of cells, possibly performing a mixture of both command and control, and with all but the lowest level of cells generating objectives for their subordinates. In general, command cells at intermediate levels within a command chain receive and produce hybrid tasking. They are presented with plans comprising a mixture of high level objectives plus some method, which will be transformed into lower level plans (lower level objectives plus much method). [Ref. 47:p. 73]

Hybrid tasking has two major implications. One is hybrid incoming command messages which must be analyzed to discriminate between the different kinds of message statements (objective and method) so that they can be handled appropriately. The other is hybrid outgoing messages which imply an ability to decompose a high level objective into a set of intermediate objectives. [Ref. 47:p. 73]

Command systems consists of hierarchical networks of decision makers which provide commanders with the means of controlling and directing the execution of complex tasks; this is achieved by partitioning the tasks into set of similar tasks for serial or parallel execution by parts of the command system [Ref. 46:p. 65]. Because there is a limit to the size of command task which can be performed by a single command process, it is preferable to devolve some responsibilities, together with authority over some force resources, to subordinate commanders.

Command chains within a distributed command system can be represented by the interconnection of separate C–processes. Each C–process will have a declared responsibility within this structure. A example chain of command is shown in Figure 3.10 [Ref. 47:p. 79].

> The high level commander C_0 has created two subordinate command posts, C_1 and C_2, and assigned to them a number of controllers (C'11,...C'22) and resources (R_{11},...R_{22}). The high level commander C_0 responds to the assigned tasks A...Z by producing a high level plan (P_0) which in general, will involve the participation of both groups 1 and 2. The specific task for each group, within the context of the overall plan P_0, will be defined by objectives 1 and 2 (O_1, O_2). The subordinate commanders C_1 and C_2 must in turn produce lower level plans (P_{11}, P_{12} and P_{21}, P_{22}) aimed at fulfilling their respective objectives. Each lower level plan will be assigned to a controller responsible for implementation of that plan. [Ref. 47:p. 75]

The purpose of co–ordination (C_3) is to ensure co–operation between co–existing command and control processes in other that the force accomplish its total task with the minimum of internal conflict. Considering the role of C_3, the C–process is tasked, via objective O_3, with co–ordinating aspects of the activities of group 1 and group 2. The plans for C_1 and C_2 (P_{11}, P_{12}, and P_{21}, P_{22}) are copied to C_3 and incorporated in C_3's world model which can then predict the combined outcome of these plans. This prediction will be monitored. When prediction of undesirable situation is detected, the co–ordination process may be expected to submit proposals for solving the problem. The procedure for generating such proposals is identical to that for command. If however, the proposal is rejected by C_1 or C_2, then C_3 must issue warning (W_3) of the impending problem and refer to a higher authority for resolution. There exist many forms of co–ordination, some being resource oriented, others being objective oriented. [Ref. 47:p. 75]

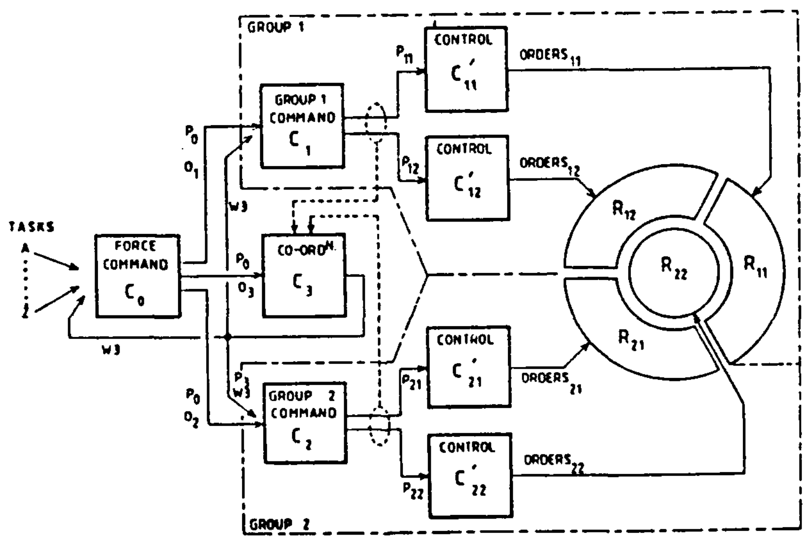


Figure 3.10 Distributed Command Organization: An Example

Summarizing Galley's discussion, transformation of command and control processes can be mainly the task allocation to the subordinate command posts, and resource allocation within a command post corresponding to the task, and coordination, while the perception process assess the situation by processing the raw data and provide information to command and control process.

IV. APPROACHES TO C^3I SYSTEM DEVELOPMENT

A. SYSTEM CONTEXT ANALYSIS

1. Role of Time in C^2

In a typical discussion of "command and control", it is taken as axiomatic that the information presented to the commander must be "timely" as well as accurate, complete, etc. During the battle, the commander has a deadline to accomplish a task by, and some required time to perform that task. There must be a balance between the time demand and time supply. Col. Savkin represented this relationships using a mathematical formula [Ref. 48:pp. 183–184]. He used the critical time T_c for the deadline, T_o for the operations time required to perform an order of task, and T_{con} for the cyclic time to be spent to command and control the task. Then the sum of T_o plus T_{con} must be less than T_c. Based on this concept, C^3 system must meet the next equation state:

$$T_{con} < T_c - T_o$$

If this inequality is fulfilled, then it can be boldy stated that control is being accomplished efficiently, otherwise one must try to decrease T_o or T_{con} up to the required level.

The measurement of time T_c, T_o, and T_{con} can be estimated by analyzing the threat, the capability of subordinate operational units, and the existing C^3 system. When a event occurs, the C^3 observation subsystem will estimate the time sensitivity of the threat. For example, assume the threat is

identified as a fighter, then the critical time available to respond to this threat is limited to a couple of minutes. Now, the commander has to make a decision about the types of his response. Assume he decided to use a missile to solve the problem. Then, according to the characteristics and performance of the missile, the missile needs some period of operations time from tracking to destroying the target. It will take a couple of minutes, too. Both T_c and T_o are determined. Now, if the commander has the fire button to control his missile launcher on hand, the control time to perform a fire direction is Zero. But, the normal military organization has some level of chain of command to control its assigned forces. So, the control time T_{con} will be affected by its organization structure. In this example, the commander already used his time for decision making to select a response type of missile rather than a friendly fighter. The total T_{con} is the sum of decision time and communication time through chain of command. This is well represented by Schutzer's work: *C^2 Theory and Measures of Effectiveness* [Ref. 49:pp. 139–141]. He used t_{cs} as T_{con}, t_a as T_o, and t_p as T_c. The t_{cs} is the control system time that is the time from the event to which the orders are received by the forces in a tactical operational level. A good C^3 system will reduce this command and control time more than a poor system does. The t_a is the time between response initiated and response implemented at tactical level (t_m) plus the time that the response is executed (t_r). The t_p is the time from a event occurs to the response preempted. The t_a and t_p are determined by the near–uncontrollable factors. If the commander has preplanned well, of course, his forces will be prepositioned, and the time required to move his maneuvering forces or to fire his firing assets will be reduced. But the threat and missions are ad hoc faced or assigned on the commander. Then the command and control time must be adjusted properly to give enough time to his

operational level forces. A complete C^3 system will perform a full C^2 process during the problem solving phases. And each steps take a time. So the total t_{cs} will be the sum of time that is spent in each steps of C^2 process. The sequence of theses events and time intervals between them is shown in Figure 4.1: Savkin's Command and Control Time Line. Total prior time to take actions will be

$$t_{cs} = t_d + t_{wc} + t_{cd} + t_{cc}$$

where:

t_{cs} = total system control time up to a response initiated

t_d = the event detection time

t_{wc} = the warning communications time

t_{cd} = the command decision time

t_{cc} = the command communications time

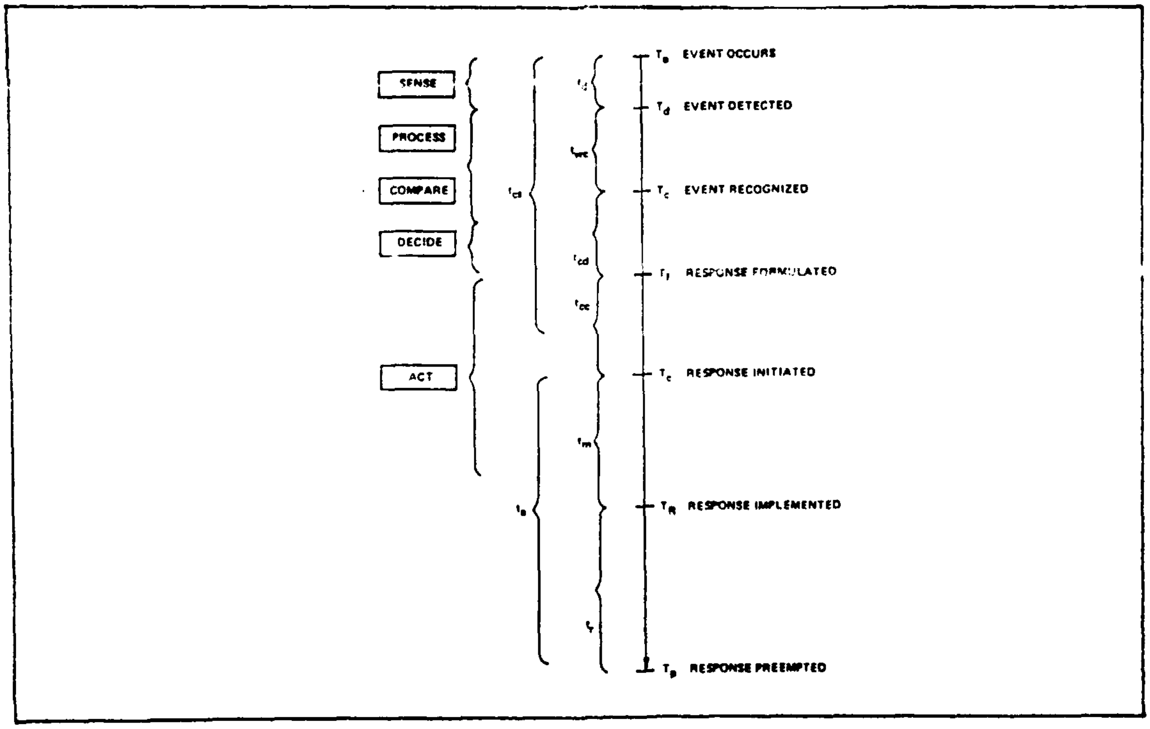


Figure 4.1 Command and Control Time Line

An event, at time T_o, initiates the situation. When the commander has recognized the situation, formulated a response, and his forces have received their direction, the response will be implemented at a time T_R. If T_R comes before T_p, the response is successful or at least appropriate. If T_R is later than T_p, because the higher level commander uses too much time for decision and command, the response has been preempted and will fail or be inappropriate. In the dynamic battle situation, there are more than one cycles of C^2 process. The higher level command structure has a deep chain of command, and the operational level command structure has a single cycle of C^2 process. Let's call this the depth of the chain of command. Then the total time to respond to a threat in N–level chain of command will be represented by Figure 4.2.

From the Figure 4.2, the total mission accomplishment time (C^2 time plus weapon system operation time) to respond against a event is

$$T = \sum_{i=1}^{n} \left[T_o^{(i)} + T_d^{(i)} \right] + T_e^{(1)}$$

where:

T is the total response time

$T_o^{(i)}$ is the observation time in the i_{th} level command

$T_d^{(i)}$ is the decision time in the i_{th} level command

$T_e^{(i)}$ is the execution time in the i_{th} level command

$T_e^{(1)}$ is the weapon system operation time at the tactical bottom level.

Based on the internal functions of each C^3 subsystem described in Chapter II, those T_o, T_d, and T_e in each subsystem will be subdivided in detail. If the processing time in the detailed steps of each subsystem is reduced and the depth

of chain of command is reduced, the operational level commander can have the more time to implement and execute the response. The former depends on the technology of computer, communications, and human operators of the information system. On the other hand, the later one depends on the structure of the force organization and commander's problem solving way. The first one is called the system engineering approach and the other one is called the organizational approach.

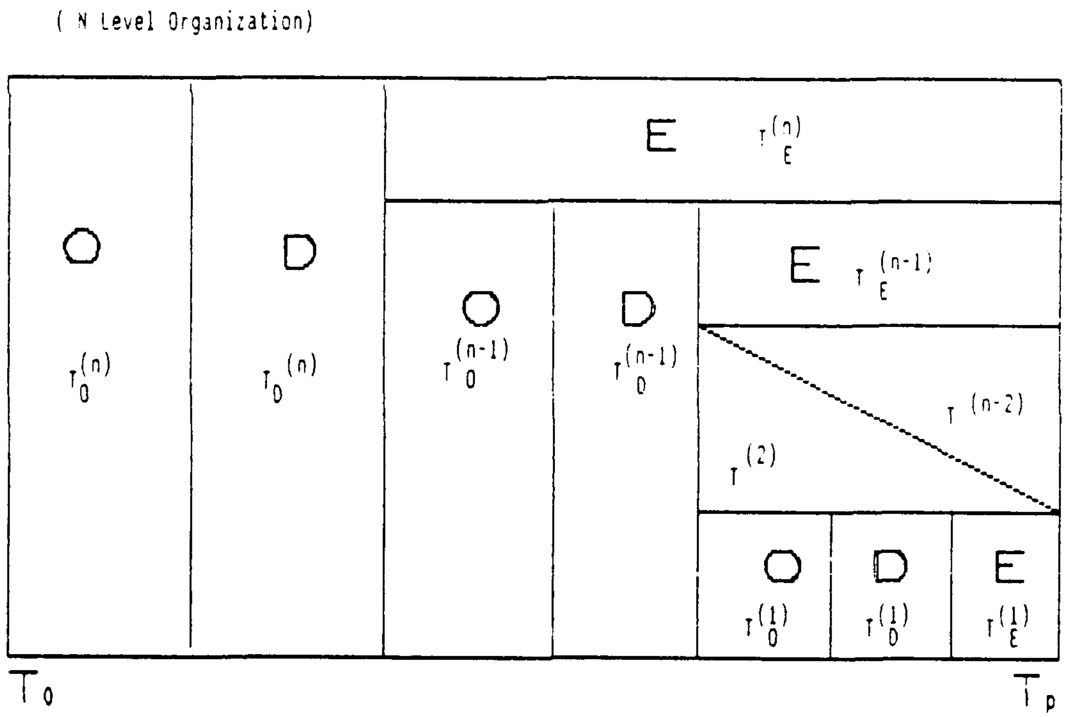


Figure 4.2 Time Allocation in Multi–Level C^2 process

2. Uncertainty in C^2

The purpose of collecting information and intelligence data is to reduce the uncertainty in decision making. While the uncertainty is reduced by a good intelligence data, the intelligence data itself will contain uncertainties. Also uncertainty is added in the processes of information collection, analysis, and distribution. So it is unlikely that uncertainty can ever be removed completely from decision making, even when voluminous data are collected. [Ref. 50:pp. 10–11] Generally, the more data a system has, however, the more value of information it has. And the more a system has time to process, the more the system has the input data and the value of information. Figure 4.3 describes this phenomena.

In Chapter II, the uncertainty was defined as the difference between the required information to perform a task and the available information at a given time. In terms of the task of the decision maker, the degree of uncertainty at a given time must be acceptable. This value of degree will be represented by its probabilities. Lindley described the procedure of coherent decision making with the following statement [Ref. 50:p. 14]:

> "... there is essentially only one way to reach a decision sensibly. First, the uncertainties present in the situation must be quantified in terms of values called probabilities. Second, the various consequences of the courses of action must be similarly described in terms of utilities. Thirdly, that decision must be taken which is expected–on the basis of the calculated probabilities–to give the greatest utility."

Lindley states that uncertainty about situation must be quantified with a value of probabilities and course of actions must be quantified with the value of utility. Then the decision making will follow the utility function with the input of probability of uncertainty under the constraint of time.

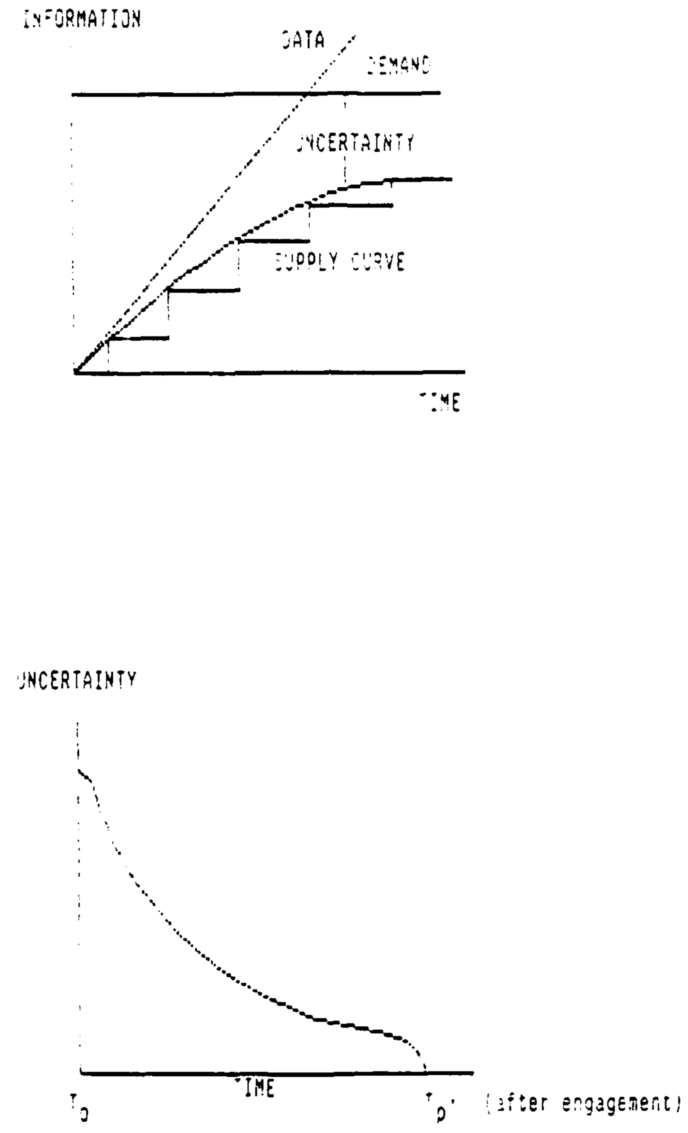


Figure 4.3 Information Rate on the Time Line

In the military situation, commanders will ask "location of the object, the size of the object, the speed of the object, and the intention of the opposing force, etc.". But, the answer will be limited to the boundary of the real location, the real size, the real speed, and the real intention. In other words, the available information has an amount of deviation or fraction around the real factors. In decision making, some amount of deviation or fractions are allowed based on the significance of the decision's outcome. So, if the deviation between the required information and available information can be measured by the normal statistical methods, uncertainty can be represented in a quantitative manner.

However, information has two attributes. One is that it describes something. The other is that the description has degrees of accuracy. The descriptive attribute will be used to measure the utility and the degrees of accuracy will be used to measure the risk while making a decision. For example, assume that a decision about the target allocation requires information such as the expected number of targets in his responsibility area and its probability. Then the answer will have such a form that the number is $X \pm \Delta X$ with Y percentage accuracy. Here, the number $(X \pm \Delta X)$ will be used to develop the course of actions, the value Y, its probability, will confirm the utility functions of the course of actions. The value ΔX is the deviation between the required information and the available information, and the value Y becomes the probability of information accuracy. The definition of uncertainty is the difference between the required information and the available information. Then, the value of uncertainty about one object will be measured by its description deviation and the gap of probabilities between the required accuracy and available accuracy.

The effects of both types of uncertainty in decision making will be divided into two sub types. One is that the significance of information, that is, the probability of accuracy is preset by the policy or decision criteria according to the types of decision maker: risk taker or risk avoider. For example, in the case of missile control, the significance must be close to 100 percentage, and the infantry unit control may require less significance. Once the significance is set, the available information will describe the object with some deviation and its probability. Then according to the balance between the deviation in its description and probability between the required and available information, the uncertainty will be used to develop course of actions. The other is that the deviation of description is preset. For example, the location of target will be described by the circle with the radius 300m centering a point. Based on the effect range of the fires, the radius is limited to 300m or 30m. Once the required deviation is set up, the available information confirms the accuracy, and is used to measure the risk.

Let the mathematical form of uncertainty be the 1 by 2 matrix of deviation and probability, then the uncertainty will be represented such as:

Uncertainty $= (X_u, Y_u)$

where:

X_u = P(required information)– P(available information)

Y_u = Deviation of description of available information

The utility function, of course, must be formulized properly to be applied to the unique military situation, that is, the dynamic situation (or stochastic model). Also, the utility function will be determined by the various types of decision

and the causes of the uncertainty case by case. So a good utility function highly depends on the study of operations research about military decision making model.

The significant influence of uncertainty through C^3 system architecture is placed in the requirements of uncertainty in the structure of hierarchical, distributed C^3 information network. If the information is examined by timing, and precision needs of different levels in the C^3 hierarchy, then it is apparent that the lower levels require timely and precise detailed information, while the higher levels require the less detailed overall picture that evolves in a slower time scale. Figure 4.4 shows the the requirements at different levels. [Ref. 51:p. 130, 134]

INCREASING AREA OF INTEREST AND RESPONSIBILITY

COMMAND LEVEL	INFORMATION INTERESTS	REASONS
TACTICAL	General force dispositions	Situation Assessment tactics
INTERMEDIATE	Track Picture	Threat assessment sensor and weapon tasking
COMBAT	Isolated Tracks	Engagement

INCREASING ACCURACY AND TIMELINESS REQUIREMENTS

Figure 4.4 Information Requirements of Different Command Levels

As shown in Figure 4.4, the lower the level of command is, the higher the density of the information is, and the higher the level of command is, the more the diversity of the information is. It is because each level of organization makes different types of decisions, and carries out different missions. And these decisions are related to its threat and the expected response types against the threat. So the required information will be represented by the information demand function:

$$
\begin{aligned}
I_D^{(i)} &= f(\text{threat or mission}) \\
&= g(\text{decision type or response type}) \\
&= \left[X_d, Y_d, Z_d \right]
\end{aligned}
$$

where:

X_d = degree of description of required information

Y_d = degree of accuracy of required information

Z_d = diversity of required information

In the equation above, i is the i_{th} level of command. In the real world, however, it is impossible to measure the total uncertainty about all activities in an organization. Fortunately, it is not necessary to measure the total uncertainty, because the uncertainty is used in making a decision about an action among the various activities within an organization. So the term i is equivalent to i_{th} type of decision.

On the other hand, in order to meet this pattern of requirements at each level, different levels of command will require different types and number of sensors and its functions. The density and diversity of information supplied to the decision making system at i_{th} command level in N levels command structure will be represented by the information production function $I_S^{(i)}$:

$$
\begin{aligned}
I_S^{(i)} &= f^{(i)}(T, N, P) + g\left[\sum_{j=i+1}^{n} I_S^{(j)}\right] + h\left[\sum_{j=1}^{i-1} I_S^{(j)}\right] \\
&= \left[X_s, Y_s, Z_s\right]
\end{aligned}
$$

where:

$I_S^{(i)}$ is the information available in the i_{th} level of command

T is the Types of sensor

N is the Number of sensors

P is the Performance of intelligence analysis function

X_s = the degree of description of available information

Y_s = the degree of accuracy of available information

Z_s = the diversity of available information

f = information production function within the i_{th} level

g = information support function from the higher level

h = information support function from the lower level

The affect of variable T, N, and P to the information production function is shown in Figure 4.5.

Information from the $(i+1)_{th}$ level command will determine the boundary of information of the i_{th} level command that makes the diversity of information narrower, and support an amount of density. Then, its own information processing system in i_{th} level command will provide more information and reduce the uncertainty. S› the f–function represents the capability of the intelligence analysis in a C^3 system.

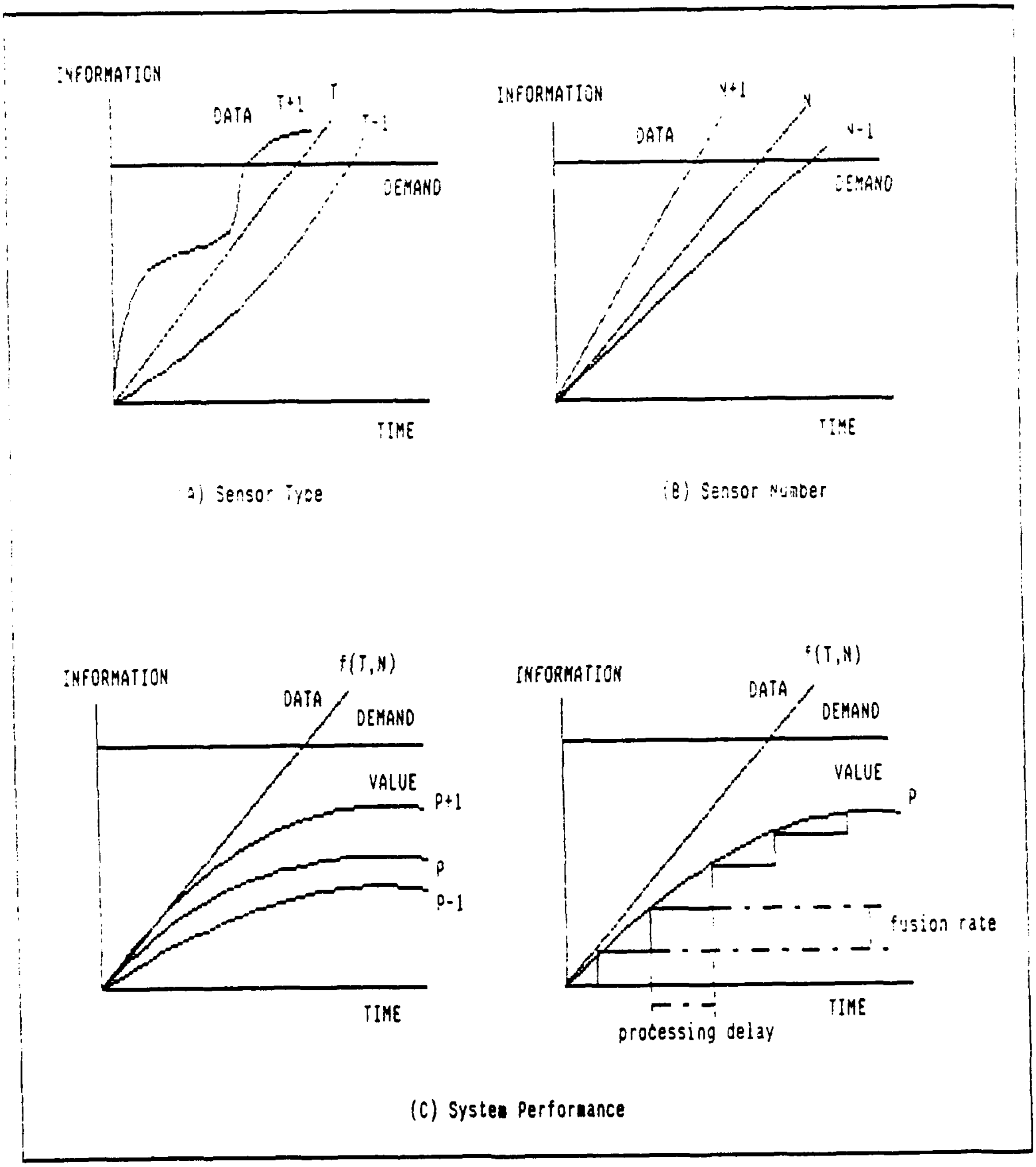


Figure 4.5 The Variables of Information Production Function

Given the general pattern of spatial and temporal certainty requirements in different levels of command, the most appropriate data distribution structure could be determined. Existing distributed command and control systems are usually structured on a tree principle that is orderly and easily controllable, both in the upward reporting and in the downward dissemination of orders. But, there is doubt whether that structure is well suited to information exchange.

An extended structure with cross–links at the intermediate levels or a virtual network through overall structure could be considered in C^3 system networking design. The g–function depends on the structure of C^3 information system network from the top level command to the i_{th} level command, and h–function depends on the structure of C^3 information system network from the i_{th} level command to the bottom level command.

Uncertainty is used in decision making stages case by case. So, the uncertainty must be represented in terms of both the decision type and the level of organizations. The attribute of uncertainty related to this decision type and its organizational level will be represented by its diversity. Kinds of the required information increase as the complexity of decision increase. Also, the kinds of information decrease as the mission is transferred down to the weapon control level. The kinds of information will be represented by its diversity. The probability of uncertainty in the i_{th} decision type in the j_{th} organization would be formulized with its deviation and density of all individual diversities between those of demand and and supply.

$$U^{(i,j)} = \sum_{k=1}^{m} f\left[X_u^{(k)}, Y_u^{(k)}, Z_u^{(k)}\right]$$

where:

m is the total number of diversity in i_{th} decision type

$X_u^{(k)}$ = the deviation of description in k_{th} diversity information

$Y_u^{(k)}$ = the difference of probabilities in k_{th} diversity information

$Z_u(k)$ = the k_{th} diversity in the i_{th} decision type in j_{th} organization

In the equation above, the role of C^3 system can be interpreted in terms of uncertainty such that, when the commander makes a decision, the C^3 system must have the capability of filtering information narrowed down to a specific focused area to the level of certainty corresponding to the i_{th} decision type. And, the C^3 system must be organized to correlate information effectively from the various sources for the diversity of certainty to some acceptable level corresponding to the j_{th} organization level.

3. Quality of C^3 System Product

The role of time and uncertainty in a battlefield is discussed as constraints for C^3 system development. One product out of C^3 system operations is decision. In turn, it is converted into missions of the subordinate units. As discussed in the previous section, the decisions are carried out by individual commanders at different levels of the command hierarchy. The quality of the decisions made by an individual commander depend on the following key factors: [Ref. 17:pp. 23–24]

- The planning horizon time;
- The nature, quality, and especially timeliness of the available information (this can be greatly influenced by a superior C^3 system);

- The complexity of the tactical situation vs. the time available to arrive at a satisfactory decision (computer decision aide for the commander can help him to either arrive at better decisions within a given time limit and/or complete his decision sooner).
- The rules of engagement (these act as constraints upon the commander's decision process);
- The goals and objectives assigned to him by superior commanders at the strategic planning phase;
- The commander's available resources (these again act as constraints to his decisions);

Focusing these factors about decisions, the decision process can be a resource allocation process using the available information following the battle doctrines under the time constraint. On the other hand, the word "control" in C^3 systems refers to the function that indeed the preplanned courses of action are more or less being accomplished in a tactical situation. To correct the undesirable deviations, real time decisions are required to control in real time the available resources [Ref. 17;p. 23]. In other words, the control function is to reallocate the resources based on the real time information upgraded since the initial implementation of the preplanned courses of action. Real time information requires the real time surveillance and real time communications. Thus the quality of a C^3 system used by individual commanders at each level of command depends basically on the real time surveillance system and communications system used for the resource allocation and resource control. But the global C^3 system must includes all organizations from the decision making level to decision implementation level. Then the quality of overall C^3 system depends on

- the organization of resources for a certain decision (grouping part of force organization),

- The organization of authority to be allowed to use the resources (command structure),
- the social communications network among humans and positions (control mechanism)
- the virtual network and real time performance of information system (intelligence capability),
- the technical communications network and its real time capability for the effective force control and information exchange (communications link)
- the decision–oriented applications process (transformation utility).

B. PRINCIPLES OF APPROACH

1. Time–Uncertainty Distribution in C^2 Process

Chapter III stated that the time is distributed through the C^2 process in multi–levels of the chain of command from T_0 to T_p, and the uncertainty requirements have different patterns in different levels of command which is represented by both density and diversity of information. Also, as time flows, the value of information increases. So, along the time line, the uncertainty has a decreasing form while observation subsystem is in operation. However, during the decision time, even while the uncertainty is still being reduced, the commander will make a decision using the constant uncertainty as the same level of the observation system. Thus the level of uncertainty will stay on constant value temporally. In the next step of C^2 process, this uncertainty will be narrowed down and a higher density in turn through the information processing system in its level. Figure 4.6 is depicted to describe this Time–Uncertainty productivity in a C^2 process in a dynamic battlefield.

Each level of a force organization has its own uncertainty requirements pattern of density and diversity, and command and control time requirements of a control system. And the requirements depend highly on the type of decision of the organization against the threat. The decisions that are related to the infantry unit in ground forces has less time sensitivity than that of the Air Forces. The decisions of higher level command require wider diversity of information than that of the lower level command, while decisions related to a missile control mission require the more density of certainty about the target than that of the ground firing weapons. So there must be a distribution rate of time and uncertainty corresponding to each type of decision and its follow on missions.

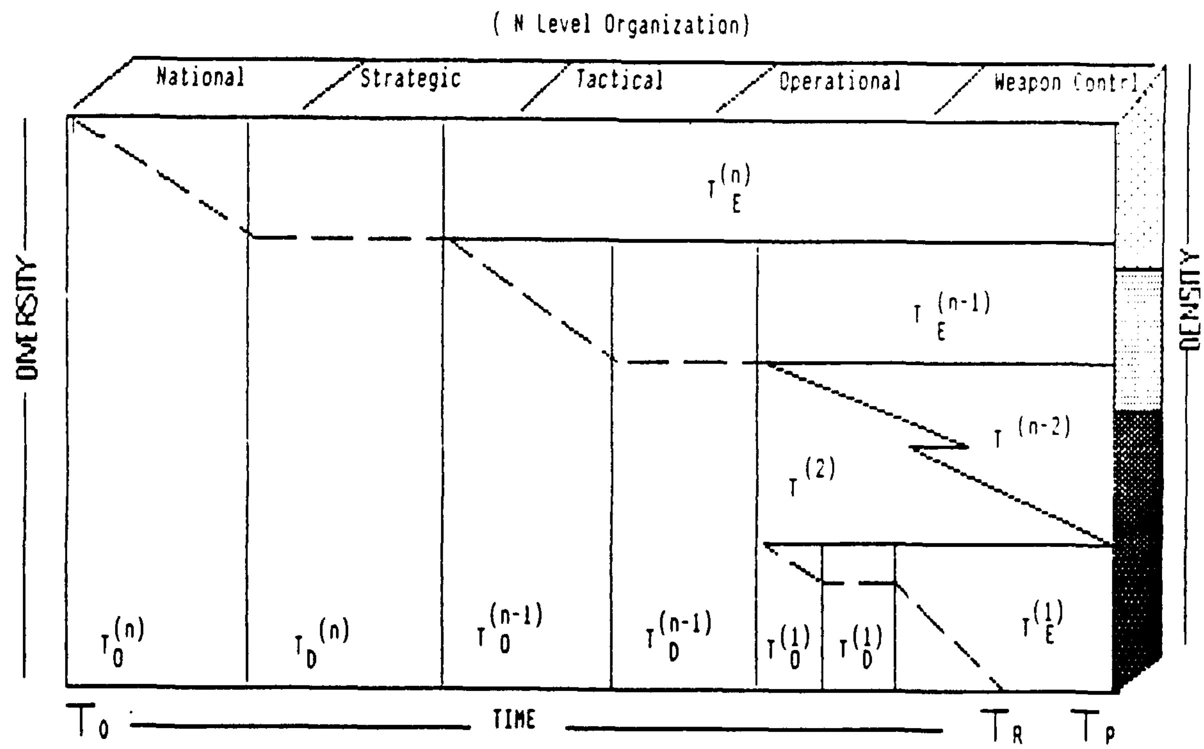


Figure 4.6 Time–Uncertainty Plot in C^2 Process

Assume the commander in an unified command is faced with an unrecognized flight object in his area of responsibility. In order to solve this problem, the commander has to make an informational decision of the identification of the object, the organizational decision of task force formation, and operational decision of course of action, etc. Then, each C^3 subsystem must operate in cycles to make decisions and control the stages. Here, the time through the C^3 process from the sensor to the unified commander, from the the unified commander to Ground Forces Long Range Missile or Air Force Fighter Group must be short. Then the time distribution rate to the intermediate command between the top level command and operational firing stations must be close to zero. This rate is determined by the weight of the effect of each subsystem in each level of command. The same concept is presented in Lawson's work: *The Role of Time in Command and Control System* [Ref. 52:p. 9]. In his work, time T is defined as the weighted average of the response times to several different stimuli, i.e.,

$$T = \sum_{i=1}^{n} T_i W_i \qquad \text{and} \quad \sum_{i=1}^{n} W_i = 1$$

where:

T_i = the response to the i_{th} stimulus type
W_i = the weight of that stimulus in the total environmental set.

Adopting this in the response time in multi–level dynamic C^2 process, each time to respond against an event must be:

$$T_o^{(i)} \leqq \left[T_p - T_e(1)\right] \cdot W_o^{(i)}$$

$$T_d^{(i)} \leqq \left[T_p - T_e(1)\right] \cdot W_d^{(i)}$$

$$T_e^{(i)} \leqq \left[T_p - T_e(1)\right] \cdot W_e^{(i)}, (i > 1)$$

$$T_e^{(1)} = t_m$$

T_p is the time length between the time that an event occurs and the response is preempted. The time length between the time that a response is initiated and the response is implemented is designated t_m. $T_e^{(1)}$ is the execution time in the weapon control level. So the time is the same as the weapon control time t_m. Then the total time to implement a respond (T_r) against a event will be:

$$T_r \leqq \sum_{i=1}^{n} \left[T_p - t_m\right] \cdot W_o^{(i)} + \sum_{i=1}^{n} \left[T_p - t_m\right] \cdot W_d^{(i)} + t_m$$

In some cases, if one intermediate level of command has the low weight rate in its observation function and decision function while carrying out the mission, the value of W_o and W_d will be zero, and the value of W_e will be close to zero. Then the C^3 system in this case must be organized with a kind of functional virtual network, with the organization having a hierarchical tree chain of command. The intermediate level of command will be used only as a link node to transmit orders, directives, or tactical data. At the same time, the information processing rate must be fast enough to cover the small amount of time available by the time weight rate.

On the other hand, at the lowest level, the weapon controller is only interested in the target or targets he has to engage, and he requires relevant information to be accurate. This in turn implies that the tasks of radar/target acquisition, correlation of local and remote tracks, and identification must also be precise and quick. [Ref. 51:p. 130] The diversity of information would be almost a few simple quantitative units such as the velocity, the location, the size, or the identification of the object. Then the density of the individual diversity will be calculated by its probability values.

Assume that the commander wants to know the exact location of flights for resource allocation and higher probability when the available information describes a big deviation in its location boundary and further a low probability. One solution is to increase the number of sensors, or to improve the performance of the information processing rate. But this solution must be preplanned prior to engagement. The C^3 system must be able to analyze the expected mission in advance and support the commander in the planning stage.

The other solution is to wait until the observation subsystem provides enough information. Is that possible? There is, however, a problem in military decision making. When there is a conflict between a time constraint and required information, how does the system optimally support decision making. For example, assume that a task requires information with 95% of certainty, but, the C^3 system in a level produces information with 90% of certainty. Then, there is two possibilities: to make a decision with some risk or wait a time until getting 5% more of certainty breaking the time constraint. It depends on the commander. Both have its advantages and disadvantages.

But, if the lower level command has the capability to control this uncertainty gap, that is, intelligence analysis capability to cover that, the higher level commander can make a decision while meeting his time constraint. Also, if the commander has a flexible span of control over his subordinate forces, he will make a decision in a given time and make a judgment after dissemination of his decision and control his forces with feedback mechanism. So, regardless of the decision making model of the system, the good C^3 system will solve this conflict. It does not mean, of course, that a good decision making model leads to a good utility function, and this utility function in turn drive a sound decision making.

2. Methodology to Improve C^3 System

So far, it is recognized that the time–uncertainty requirement is the basis for design of the C^3 system in both its organizational structure and its information system engineering. The design of a C^3 system must be oriented by the decision types in an organization. In other words, the decision type makes the time –uncertainty distribution requirements equations. Then the requirements drive the C^3 organizational structure, and the C^3 information processing rate and architecture.

For example, at the lowest operational level, the data communications structure must allow a rapid dissemination of tactical data, and the computer processing capability must produce an individual utility function with a high computing rate to reduce the uncertainty about a few individual quantitative diversities. Also, the interaction procedure for coordination must be as simple as possible to reduce the response time. In some cases, some intermediate level stages in C^3 subsystem will not be considered in the hierarchical chain of command, that is a virtual network for information exchange or first decision and later judgment.

The higher levels of command are concerned, less with individual targets or tracks, and more with formations and raid sizes, directions and speeds of approach. The type of certainty required here is certainty in interpreting the overall track picture which depends rather less on the detailed accuracy than on its completeness. The track accuracy and timeliness requirements are less stringent at this level. [Ref. 51:p. 131] Thus, the communications system must have a large volume of information traffic capacity, and the computer processing capability must support the integrated utility functions for various situation assessment. Also, the interaction groups must be well organized and operated for the better situation assessment and unity of effort in mission control.

C. C^3 ORGANIZATIONAL APPROACH

In Chapter II, the relationships among the organization, information system, and decision and control system was defined as such that an organization produces the information, and decision system makes a decision using the capability of an information system which processes the information, then the operational system controls the organization toward to the objective following the decision. Thus the primary functions of an organization are the information handling (information exchange, information processing, etc.) and control of organization (either objective–oriented or resource–oriented control).

1. Organize The Forcepower

Organizing the force consists of grouping the elementary units which are dispersed geographically and building the network with communication links and operations procedures. While grouping the forces, the level of organization and the type of forces will be based on the expected mission. And the operations procedures will follow the concepts of the effective information exchange and easy force control.

Given a set of positions duly designed in terms of job specialization, behavior formulization, training, and indoctrination, grouping means that, positions are grouped into units, each under its own manager, and units clustered into ever larger units under their own managers, until the whole organization comes under a single manager–the chief executive officer at the strategic apex. Thus, a hierarchy of authority is constructed through which flows the formal power to control decisions and actions. That hierarchy is generally represented by an organizational chart. [Ref. 39:p. 282]

Grouping units, two major questions arise in the design. First, on what basis are positions and units grouped into larger units, and second, what size should each of the units be?

Positions and units can be grouped on two fundamental bases. The first is grouping by function such as by knowledge and skill, and by work process and function. Here grouping is done by means, by the intermediate functions the organization uses to produce or support the production of its final outputs. The other is grouping by market such as by outputs, by client, and by place. In this case, grouping is done by ends, by the features of the markets served by organization–the products or services it market, the clients it serves, the places where it serves them. [Ref. 39:p. 283]

The size of units is historically described in terms of the "span of control". The classical literature says "no supervisor can supervise directly the work of more than five or, at least , six subordinates whose work interlocks" [Ref. 39:p. 284, quoted from Urwick].

But, turning to an analysis of the coordinating mechanisms other than direct supervision, the explanation of variation in the unit size has two clear

relationships. First, the greater the use of standardization (of any kind) for coordination, the larger the size of work unit. It stands to reason that the more coordination within a unit can be achieved by standardization. The second relationship is that the greater the need for mutual adjustment, the smaller must be the size of work unit. [Ref. 39:pp. 284–286]

Tasks, loosely coupled, can rely on the standardization of skills for coordination, and so it allows the professionals to work relatively autonomously in large units. When tasks are rather complex yet tightly coupled, neither direct supervision nor any form of standardization suffices to effect the necessary coordination. The specialists who perform the various tasks must coordinate by virtue of informal, face to face communication among themselves. [Ref. 39:p. 286] So the social communications links among the positions and units may be different from the structured links of organizational chart. The organizational chart may show the shared power of authority and the division of labors or works. Communication links, in turn, must be able to support the informal coordination (information exchange) of labors as well as the direction and reports line over the chain of command hierarchy which is the shared power of authority and responsibility.

2. Design The Decision Making Organization

The issue of power structures is of interest in the design and evolution of command and control structures. As defined by Jeffrey Pfeffer, the determinant of power and influence in any organization include the following aspects [Ref. 38:p. 20, quoted from Pfeffer, 1978]:

- Formal authority – the delineation of decision responsibilities in a rational, hierarchical sense.
- Control over resources – the distribution of discretionary control over critical and scarce resources.

- Information and access – the distribution of knowledge and awareness which enables effective decision making.

Organizational design deals with the conscious distribution of these three power mechanisms within a command and control organizations. But the distribution of each type of power mechanisms must be balanced [Ref. 38:pp. 20–21]. In military organization, the information is handled by the staffs, and merged to the commander who is the decision maker. The force control is characterized by a centralized or decentralized control type. There is, however, a conflict between the military control type, which is considered as the chain of command, and the best information exchange path. The chain of command is a hierarchical structure while the information exchange path is preferred to have a virtual network.

One solution of this conflict is to build an optimal information exchange path structure, and then transform this structure into the decision making organization. The design of the information path structure must be decision oriented. Then the chain of command in an organization will not be fixed such as the hardware of a computer architecture, but flexible such as the firmware corresponding to the characteristics of each decisions.

One approach to design the C^2 organization (command and control structure) is introduced by Andreadakis and Levis using the concept of Petri net [Ref. 53]. In their work, the data flow structure is determined first and then the decision making organization design is obtained by transformation of the data flow structure into a C^2 organization.

The formulation of the design problem follows that, given a mission and a set of tasks to be performed, design a C^2 organization that is accurate, timely, exhibits a task processing rate that is higher than the task arrival rate, and whose

decision makers are not overloaded. The properties that characterize a decision making organization such as accuracy, response time, task processing rate, and workload, can be quantified by the corresponding measures of performance (MOPs). [Ref. 53:pp. 1–2] The MOPs will be discussed in the last section of this chapter. But the constraint that must be observed are that the decision makers are not overloaded, i.e., the decision maker's information processing rate F be less than the rationality threshold F_e:

$$F < F_e \text{ for every decision maker.}$$

The design methodology has four phases (Figure 4.7): [Ref. 53:p. 2]

- Phase 1 – An algorithm for generating data flow structures produces a set of candidate designs, from which a few representative ones are selected.

- Phase 2 – The activity of the individual functions or processes, the accuracy, the processing time, and the processing rate of each data flow structures are computed.

- Phase 3 – Each data flow structure is augmented and transformed into a C^2 organization in which the functions have been allocated to decision makers and the communications protocols have been designed.

- Phase 4 – The evaluation of the measures of performance of each C^2 organization is performed and then the respective measures of effectiveness (MOEs) are computed.

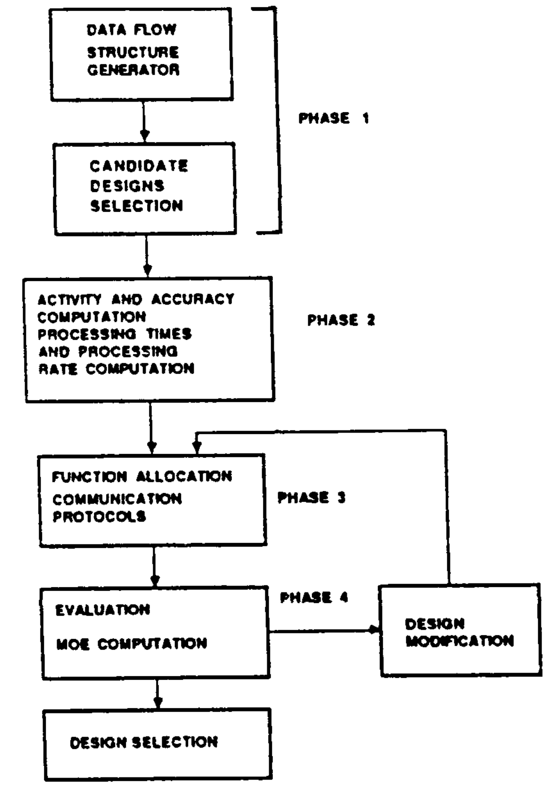


Figure 4.7 Design Methodology Flowchart

The designs obtained in this matter are revised to increase their measure of effectiveness by introducing decision aids, changing the function allocation, or modifying the protocols. The introduction of the hardware and its associated software (the command and control system), i.e., the specifications for the required decision aids and data bases as well as for the communications links, transforms each decision making organization into the corresponding command and control organization. Finally, a command and control organization is selected from the candidate designs on the basis of the greatest MOE value. [Ref. 53:p. 3]

In order to generate the data flow structure, Andreadakis and Levis used Petri net formalism. The processing stages are represented by transitions, whereas the data or information that are input or output of the processing stages are represented by places. The availability of data or information at specific places of the Petri net is represented by the existence of tokens in the respective places. The information processing includes the following five stages: [Ref. 53:p. 3]

- Initial processing [IP] – This stage receives data from the sensors and performs preliminary situation assessment.
- Data fusion [DF] – This stage receives and combines (fuses) the results of IP.
- Middle processing [MP] – This stage follows the DF stage and performs situation assessment.
- Results fusion [RF] – This stage combines the results of several MP stages.
- Final processing [FP] – This stage operates on the outcome of the RF stage and selects a response, i.e., it produces an output.

But there are various interactions between each stage, that is, some information flow can skip certain stages, and followed by the next higher stage directly. Thus there are three basic types of the permissible information flow line. Figure 4.8 shows the three information flow types [Ref. 53:p. 3].

The combination of these basic information flow types will make different kinds of data flow structures with different degree of complexity and redundancy of data processing. One example is shown in Figure 4.9 [Ref. 53:p. 6]. So the objectives of the second phase are to compute the total activity: an estimate of the processing time of each function, the accuracy of the response, and an estimate of the processing rate range of the data flow structure [Ref. 53:p. 4].

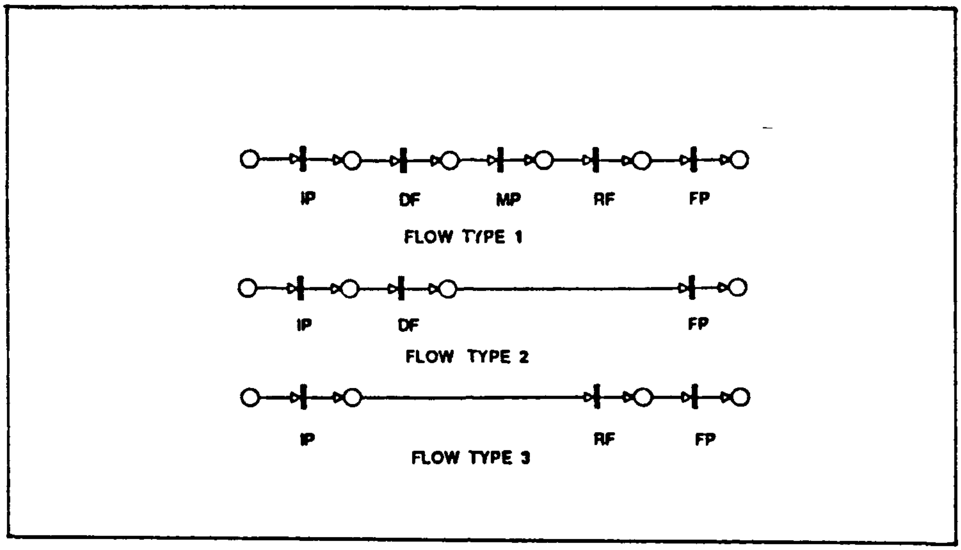


Figure 4.8 Information Flow Types

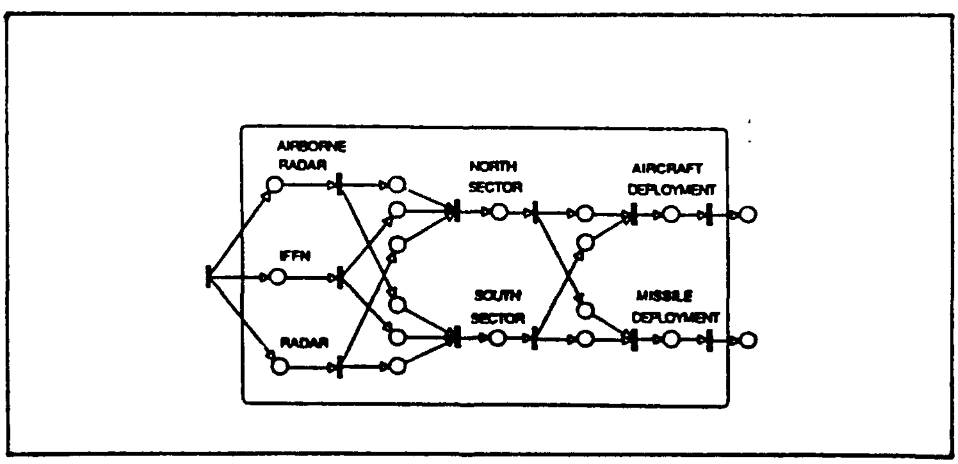


Figure 4.9 Data Flow Structure: An Example

Assuming that each transition is assigned to a different decision maker through a command and control time line, the processing time of each information flow path is the sum of the processing times of the transitions that belong to the path. The inverse of the maximum processing time is the minimum processing rate of the data flow structure. If the task arrival rate is less than the minimum processing rate, the C^2 organization that will be designed from the data flow structure is likely to satisfy the processing rate requirement. If the task arrival rate is greater than the maximum processing rate, multiple processing channels, which are copies of the basic data flow structure must be introduced, so that the arriving tasks can be assigned to alternate channels of the C^2 organization. [Ref. 53:p. 5]

The processing range obtained is, however, only an estimate of the range of the decision making organization because information flow path using Petri net does not take into account the delays along the communications links. For the complete C^2 organization, each candidate data flow structure must be augmented involving the communication links and functions, and, in turn, the MOPs and MOEs must be computed.

Function allocated to a decision maker must observe 3 requirements: [Ref. 53:p. 5]

(a) They must be related through an input–output relationship, i.e., the output of one function must be the input of the next function performed by the decision maker so that each decision maker processes information relevant to the same subtask;
(b) They must belong to different slices on the Petri net so that they observe concurrency; and
(c) They must conform to the specialization of the respective decision maker.

To meet the requirements, only functions that belong to the same information path will be considered for allocation to a particular decision maker. When such a set of

functions are allocated to a decision maker, a resource place is introduced that is an output place of the last and an input of place to the first transition allocated to the decision maker [Ref. 53:p. 5].

By computing the measure of performance such as accuracy, timeliness and processing rate of the candidate decision making organization designs, and the measure of effectiveness defined in the design strategy, if the result is not satisfactory, the design must be modified for the increase of the result value. The modification may include alternative function allocation, introduction of decision aids and databases and revision of the communication protocols. [Ref. 53:p. 5]

Once a decision are made, it is followed by execution of the decision and a control function. So the modification phase must consider the control mechanism because the best information exchange path may be different from the control network. The dynamic control function of C^2 organization may interrupt the processing stages by the random inputs to a particular nodes. Also a decision by one C^2 organization may be interrupted by the output of the other adjacent C^2 organization. It is the coordination problem between multi–level decision making. In this case, the control mechanism is more significant than the information path. The technique to compensate for this friction is follows.

First, the significance of functions allocated to each decision maker will be rated and counted in the phase of communication protocols definition and capacity allocation.

Second, the resource–oriented decision making will prevent the relevant decision making similar to each others. The authority to use resources is limited to a few decision makers, and the information base of each decision making nodes marks the power of the resource control, then decision aids will check the authority.

Third, in task–oriented decision making which is used in this design methodology, decision–oriented information base will be used to reduce the delay time caused by random control interrupt. The information base of each decision making nodes will be generated and structured in support of problem solving related to each decision type rather than problem reflection related to an event. If a processing stage is interrupted by a random input, the decision maker can easily switch his processing result to the other types corresponding to the order of control, because the information base describes the current transition processes in each stages.

For example, each newspaper reporter collects information from various sources, then the columnist writes an article in his interest area which is on the significant issue of the day. Then a manager of an economic firm reviews all articles related to this event through all articles which are related to this topic from the past article to the current article. But these articles may appear in politics page as well as economic page. It is not efficient to analyze and make a decision for response to this event. The manager will refer to the script that has been organized under a expected decision. The script type information base is preferred to the newspaper type information base.

D. APPROACH FOR C^3 TRANSFORMATION SYSTEM

Once the forces are organized and decision making organization are designed, these C^2 organization will be enhanced by decision support systems applicable to assist the decision makers or battle managers. To design the decision support systems, the battle management application models are developed in advance. This application model will be the products of combat models or command and control

model by military analysts or operations researchers. Then software engineers and knowledge engineers will implement the models into the real computer–based decision support algorithm. Remembering the models of organization discussed in Chapter III, a training system of battle managers is another area of command and control system with the same significance rate as the decision support system. The author will call the function of decision support system as C^3 transformation system excluding the training perspective of C^3 system.

The C^3 functional transformation system is divided into three subsystems which will perform the C^3 process. The functions of these subsystem is identical to information management, decision management, and executive management function of Thornton's conceptual architecture of the C^2 process. The input to the observation subsystem is the data from the sensor, and the output is the situation assessment. The data will be processed through various steps such as aggregation, filtration, correlation, analysis, and dissemination. This assessment is then transformed to a decision through the decision subsystem which develops a course of action, estimates the enemy's response, and evaluates the course of action with comparison. Finally, this decision will be transformed into implementation form such as fire distribution in execution subsystem through the steps of development of plan, preparation of directives and reports, and issuance of plans, orders, and reports.

1. State Equations of Battlefield

The design of C^3 system must be decision–oriented, because the types of decision makes the time uncertainty distribution through the C^3 process. Then there must be a study about what types of decisions are made in the battlefield and how these types of decisions make the requirements of time and uncertainty. Once a

general form of the answers to these questions are made, individual application models can be developed naturally.

Chapter II states that the purpose of the C^3 system is to transform the state of the battlefield into the desired state. The time and uncertainty are the constraints of this transformation function, and decision making in the battlefield is nothing else but checking the variables and comparing and controlling them under the constraints. Types of decisions will be determined by the combination of those variables, then, the decision types will make the requirements of time–uncertainty constraints automatically.

Now, what is the state variables of the battlefield in the dynamic battle situation? To find these variables will be the key of developing the C^3 system. Once they are defined effectively, the dynamics of the battlefield situation could be analyzed by operations research stochastic model methodology. Stochastic models analyze the overall system with the microstate conditions. Then, what is the steady–state equation of battlefield?

In the battlefield, C^3 system observes the change of state, then transform this into the desired state. The change of state will be observed by the occurrences of events at a given time. Social scientists say that there is a symptom before an event occurs. The symptom is represented by entropy theory. When a event occurs, the entropy of the system is increasing. Adopting this theory, Lawson used the thermodynamic entropy theory. In his work: *State Variables of a Command Control System*, he used an "Ideal Gas" analogy to describe the state of the battlefield [Ref. 13:p. 70]. His equation of state is

$$P_m \cdot V_r = k \cdot N \cdot T$$

where:

P_m = military pressure

V_r = volume to be pressured or controlled

N = number of forces

T = tempo of operations

k = arbitrary constant

It is obvious that the "military pressure" or influence which can be brought to bear is generally proportional to the number of forces involved. Similarly, if the tempo of operations is increased, the military pressure is increased. On the other hand, with fixed forces, if the volume within which they are to exert influence is increased, then the military pressure at any particular point must of necessity decrease.

Lawson used this model in a surveillance system application. He derived a relationship between the response time in decision making and the required number of sensors when the value of uncertainty stay at a constant probability. It is a great observation in command and control system analogy. However, the interpretation of those variables are still in question. What does the variable k mean, and how do you measure the tempo of operations, even what is the tempo of operations?

Let's expand this equation in more detail. The usefulness of this equation is that, if the enemy has the energy of (kNT), then the friendly forces has the pressure of (PV), vice versa. So if we can observe the enemy's (kNT), then we can measure the threat and develop a mission using the pressured energy (PV) in the responsible area. The initial state of input to the C^3 system is the enemy's $(kNT)_i$ from the environment, then the state of output from the C^3 system is friendly

forces's $(kNT)_0$ into the environment. The internal transformation function of the C^3 system will analyze the $(PV)_i$ as the intermediate media, and derive the $(PV)_0$, then the control function of C^3 system will control the $(kNT)_0$ with a certain mechanism. Figure 4.10 depicts the application of this equation.

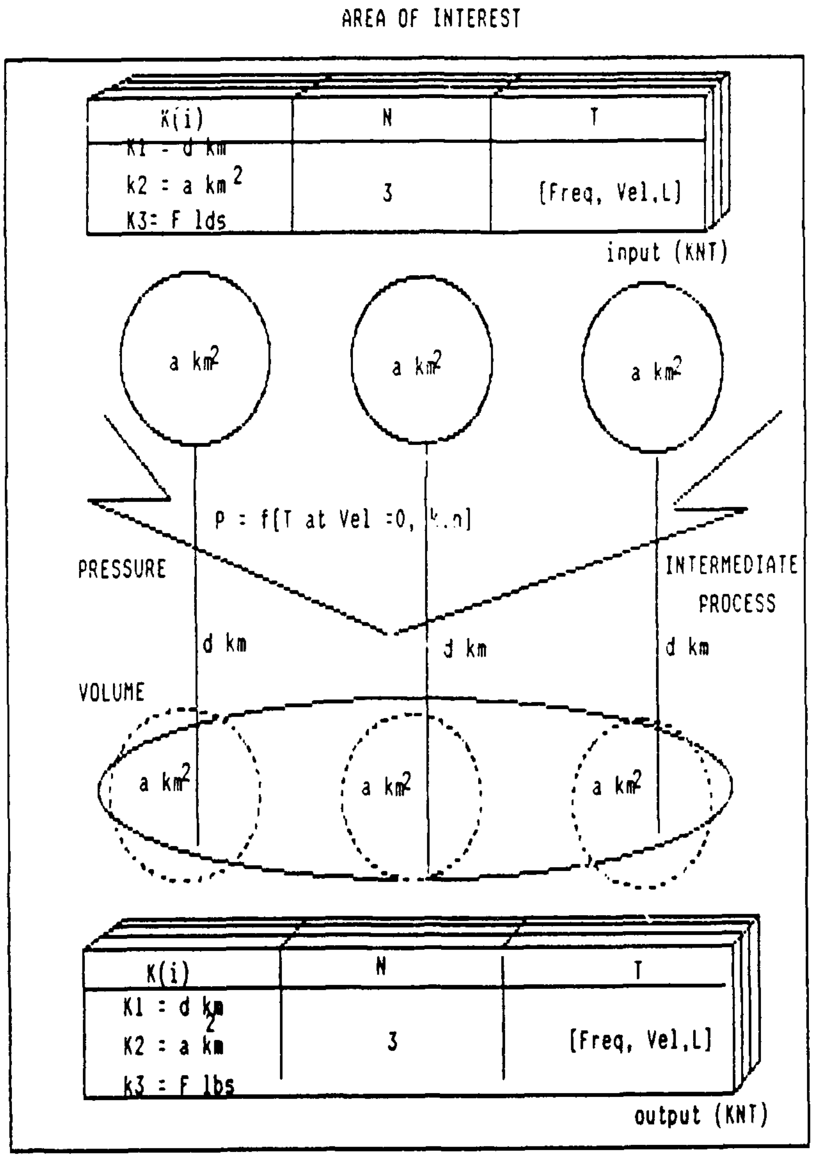


Figure 4.10 Application of State Equation

Then, what is the proper way to interpret these variables for the best application? Assume that standard military commanders follow the principles of war, then the studies of principles of war will contribute to interpreting the variables. Whether the thermodynamic theory can describe these principles depends on the interpretation of the variables in the ideal gas analogy and the analysis of those principles. The attributes of some principles are quantitative and those of others are qualitative. But, most of the principles could be described by the attributes of time of operations or events, location of objects on the time line, direction, speed, weapon's destruction power, area of responsibility, or the number of events in a given time, etc. For example, the principle of mass will be explained by the quantitative manner such as the number of weapons or forces, the firing directions of both weapons, the area of target, the hitting time to the target by the various weapons. Even though the power is same, if the area of the target is wide, then the mass decreases. Also, if the hitting velocity is small, then the mass will decrease, too. That also means it loses surprise. Let's see one more principle. Unity of command will be explained by the attributes of synchronization. Synchronization has multi–dimensional vectors such as speed, location, and direction. If some efforts are crossed together in its direction, it means that there are some conflicts in controlling those forces, that is, asynchronized. On the other hand, if the speeds are constant and the same on each, the initial position and the direction vector has the same size in each unit, then it means that it is a synchronized operation. This can be acceptable both by quantitative manner and conceptually.

Let's try to explain this example by the ideal gas analogy. Assume you have a power group. Then, the group has its own internal power. This power is the potential, steady–state energy. If this power is broken within the area of a critical

sector, then the power affects the environment. Otherwise, even though it has a lot of power, it can be disregarded. This points out that a power group will have another attribute such as its total group movement. Let the formula "PV = kNT" be the equation of steady–state of the battlefield, and let "F = ma" describe the military operations as the same as the technology of mechanical. In this case, F is interpreted as the threat, m is the power of steady–state, and a is the operational movement or principles of war. If the steady–state power stays on a constant state, that is, not on operations, it is not a threat. Now, let's rewrite the threat function using Newton's Law.

Threat = (Potential Power of enemy) x (Operations of enemy)

where:

Potential Power = Effectiveness of a force x Number of forces

Operations = Integrated rate of states change

From this concept, the variables of ideal gas state in the right side of the equation, will be determined clearly.

k = the effectiveness of a force or weapon

N = the number of forces or weapons

T = the integrated rate of group movement.

These terms in the right side of state equation will be used to analyze the threat. If it is assumed that the accomplishment of missions in the battlefield is

the fire distribution to the right place in the right time [Ref. 6:p. 58], T indicates the changes of the subordinate assets in its location. This changes will be represented by the initial location and the velocities of each individual objects, and the rate of changes will be the frequency of changes in a given time unit. In ancient times the frequency of the drum used to control the subordinate forces in the battlefield was the commander's intentions telling the maneuvering speed. The variable T will be the integrated function of frequency, velocity, and the initial location.

$$T = \sum_{i=1}^{n} f_{(i)} \left[Freq_{(i)}, Vel_{(i)}, L_{(i)} \right]$$

Now, what about the terms (PV) in the left side of the equation? This term is used to derive the missions measuring the pressure and volume to be affected by the threat. The methodology to measure the variables P and V depends on the analysis of the right side of equation. Assume that the information of a variable k has the multiple–number of description attributes such that $k_{(1)}$ describes the range of fire, $k_{(2)}$, the affected area, and there is a fire after time Δt, then the variable V after time Δt will be represented by the circle of $k_{(2)} \cdot N$ centering at the location after time Δt plus its movement path:

$$V = \left[\int_{t_0}^{\Delta t} Vel \, dt + k_{(1)} \right]_{path} + k_{(2)} \cdot N \, (C)_{area}$$

where C is the center of the circle at $(L_0 + Vel \cdot \Delta t)$

The variable P in thermodynamic theory is the movement of the particles. But, in the military situation, it can be considered as the massing of troops [Ref. 52:p. 12]. A version of this concept quantified by Colonel Krawitz, USAF in his development of the TALON war game introduced "military momentum." This is the product of what he calls the "military mass" of an element and its ability to move. The military mass in turn is a complicated function of the entity's firepower (ability to hurt others) and its ability to absorb punishment. A similar concept to Krawitz's military mass has been developed by Colonel T. N. DuPuy, USA (Ret.) in which he uses historical data to derive "effectiveness values" for various weapons and weapon systems and shows how they may be manipulated to predict which side will be victorious in combat. Using this motion of military momentum, another form of military pressure can be defined by the time rate of change of momentum. [Ref. 52:p. 13] It is the frequency of momentum in the equation above. But there are more than one frequency in the group movement consisting of many partial events. Thus the military pressure will be the sum of the frequencies. That is the "bandwidth" of momentum. The military pressure will appear in the integrated form of the bandwidth and the entire firepower.

In many cases, however, the apparent state of the environment will not change sufficiently to require a new "decision" until several events have been sensed, processed, and entered into the comparison functions. It may require the concatenation of several events to trigger the decision function to decide on a new or changed objective which leads to the choice of a new course of action [Ref. 52:pp. 9–10]. Development of a course of action can utilize signal processing filtering theory such as a high pass filter or a low pass filter for analyzing the threat and the mission allocation. The course of action against the object with high frequency must

have the ability to react for the frequent changes. For example, the course of action for the operations of enemy's special forces must be specific compared to the others. It can also utilize the utility theory in measuring the course of action with input of the entire firepower. In the military battlefield it will be represented by the effectiveness and number of the weapons or forces. So the variable P will be represented by the function of

$$P = f\left[\sum_{i=1}^{n} \text{Freq}_{(i)}, k \cdot n \right]$$

where the term $\sum_{i=1}^{n} \text{Freq}_{(i)}$ is the bandwidth of Tempo and the term $k \cdot n$ is the firepower. If the velocity variable is added to this function, this pressure will become the hostile actions. In other words,

$$\sum_{i=1}^{n} \text{Freq}_{(i)} = T \text{ (at Vel}_{(i)} = 0).$$

2. Methodology of Modeling C^3 Application Utility

The key considerations in the C^3 applications model is the way of battle managers on both enemy side and friendly side balance. If the knowledge of the human way of doing is obtained, it is possible to expect what will occur in a particular situation. And the battle manager can respond to the expected action. The complete acquisition of the knowledge is impossible. But a good knowledge engineer can produce reasonable and realistic knowledge.

When a event occurs, however, there is a set of pre–actions as discussed earlier. In addition, assuming that the battle management is the resource allocation

in a right place and time dimension such as fire distribution, the intention of the opponent battle managers can be expected and the possibility of the expected event will be quantified by the probability. If this probability meets the real action frequently, that will be the pattern of the battle managers way of doing. Once a pattern is formularized, the heuristic artificial intelligence system or semi–structured decision support system can be developed for the event expectation and resource allocation.

One approach to find the pattern of battle manager may be to analyze the movements of the resources. If it is assumed that a military operation has a pattern of force movements in its direction and speed, and that the military operation requires an amount of forcepower to accomplish the objectives of the operations, it is possible to estimate what is happening (surveillance), and decision making will be made in time what resource must be allocated to respond to this expected event (resource allocation) as well as the enemy's action. Of course, it requires that military operations such as offense, defense, deception, have some assumptions such as:

- Attacking force has the higher forcepower ratio over the the defense force.
- Attacking force has a frequent resource distribution in some pattern, i.e., there are many changes in its force locations toward the opponent place in the initial state.
- Attack has an amount of positive velocity toward the opponent side.
- Withdrawing force has the less forcepower ratio over the opponent force.
- Withdrawing force has a frequent changes in its locations in disorder.
- Withdraw has a amount of negative velocity toward the opponent side.
- Defending force has an amount of forcepower to maintain its power.

- Defending force has a slow distribution of forces in a pattern along the battle line.
- Defense has zero velocity toward each sides, but the speed exists along the battle line.

Assuming these factors, each type of tactical operations will be characterized by following conditions.

(a) The offense operations of the Red force will be characterized by:

Ratio of forcepower > 1, that is, $(\frac{P}{V})_B >> (\frac{P}{V})_R$,

Center frequency of tempo [H(T)] >> H_0, and

Velocity of movements [$\sum_{i=1}^{n} v_{(i)}$] >> 0,

where H is the frequency aggregation function, and H_0 is the experimental basis from the past pattern.

The H function observes the interval of time of each event for the same type of moving object, and plots these interval times over an object distribution axis then calculates the average interval time regarding the rate of power (threat degree) for each object type and invert this value for the frequency form. H_0 means the readiness of force for a specific tactical operations. For example, if the Red Force has changed the location of its forces forward 40% out of its total forcepower within one hour, and if it is a pattern of preparing an attack based on the past

pattern or the judgment by the commander, then the Red Force must be considered to be ready for offensive actions.

The state change time (T), the state change frequency (Freq), the bandwidth of state change (BW of Tempo) at time t will be measured by the next formula (see Figure 4.11):

$$T_E = \frac{\sum_{i=o}^{n} (\text{Event Detection Interval Time } (t_i)dt}{\text{Number of Events}}$$

where

t_o = the first event detection time

t_i = the current time

n = the number of detection time between t_o and t_i

E is the types of event,

and

$$Feq_E = \frac{1}{T_E},$$

$$BW = \sum_{E=1}^{m} Freq_{E,} \text{ (m = the last type of event).}$$

Then the center frequency of the Red Force may be measured by the highest frequency out of this BW with a rapid increase between t_i and t_{i-1} in detection time interval. If this center frequency is higher than H_0, which shows that there is a state change more than 40% out of the total force power, it will be considered as a pattern of offensive operations.

Also, the initial location (L), the number of forces (N) to be used for mission allocation at time t will be:

$$L = (T_E \cdot Vel_E)$$
$$N = m \text{ (Number of Events).}$$

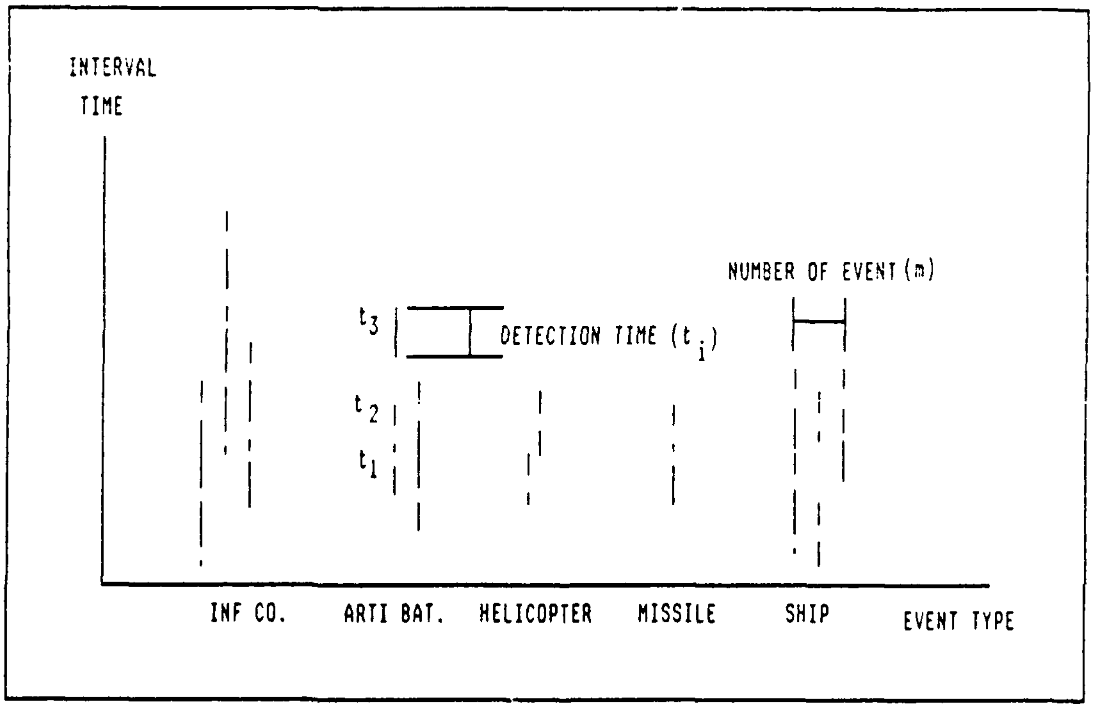


Figure 4.11 Event Detection Chart

Once these values are determined and the military pressure (P) and the volume of responsibility (V) are measured as discussed in the previous section, then the mission can be developed. That is the weapon resource allocation and target assignment. In the phase of weapon resource allocation, the variable k, which shows the destruction power, will be used to check if they matched each other, while the initial location and the velocity of a target will be considered in the target assignment phase.

(b) The defense operations of Red force will be characterized by:

Ratio of forcepower $\cong 1$, that is, $(\frac{P}{V})_B \cong (\frac{P}{V})_R$,

Center frequency of tempo [H(T)] $\cong H_0$, and

Velocity of movements [$\sum_{i=1}^{n} v_{(i)}$] $\cong 0$.

(c) The withdrawal operations of Red force will be characterized by:

Ratio of forcepower < 1, that is, $(\frac{P}{V})_B << (\frac{P}{V})_R$,

Center frequency of tempo [H(T)] is not consistent, and

Velocity of movements [$\sum_{i=1}^{n} v_{(i)}$] $<< 0$.

(d) The deception operations will be characterized by:

Ratio of forcepower < 1, that is, $(\frac{P}{V})_B << (\frac{P}{V})_R$,

Center frequency of tempo [H(T)] is not consistent, and

Velocity of movements [$\sum_{i=1}^{n} v_{(i)}$] $>> 0$.

or

Ratio of forcepower > 1, that is, $\left(\frac{P}{V}\right)_B >> \left(\frac{P}{V}\right)_R$,

Center frequency of tempo [H(T)] is not consistent, and

Velocity of movements $[\sum_{i=1}^{n} v_{(i)}] \leq 0$,

because if the big velocity of forces with low power ratio or the small velocity of forces with high ratio is abnormal.

Once the intention of the Red forces is identified, the response type will be developed by the resource allocation corresponding to the speed of each moving object, and the types of weapon, which have been observed and plotted in the function H to produce a center frequency. To reduce the response time, the mission to intercept the moving objects must be assigned to the weapons with the capability of fast reaction. One is to select the weapons with high speed or the force located close to the objects. Another is to select the type of weapons. For example, whether to use missile or aircraft is dependent on the utility of the course of action and the availability of the resources in the battle manager's level assigned corresponding to his command authority over the chain of command. So during the resource allocations, the software algorithm must compute the utility value of each course of action, and the response time to meet the mission accomplishment. To develop the utility algorithm, one can use various combat models and operation research technologies such as Lanchester equations and Markov model.

Once the algorithm of the decision support system is produced by the knowledge engineers, information requirements of the decision support system will determine the required quality of information and the diversity in each processing

stages. This, in turn, will determine the types of sensors and the number of each sensor in each decision making level through the command and control organization. Finally, each decision making organization will build an information matrix to be used by the decision support system or to be disseminated to another decision node. This information matrix will conform to the distributed decision support system, and decision oriented structure.

In terms of individual decision making in each level of command rather than group decision making over the distributed network, the key parameter of design is the display system for the commanders. After all information processing stages are completed through the information path, the final stage of decision making in each transition is finished by human battle managers. So the interaction between decision support system and human beings are very significant.

On the other hand, the distributed group decision making in the hierarchical organization requires that the key parameter of design is the information base which is used in each transition stages over the distributed network. The raw data from the various sources will be reformatted for each specific decision type. That is, the information requirements for each decision defines data necessary to a specific decision and this data will have a standard matrix so that transferable and accessible by each transition nodes related to the decision. This decision oriented information base then interact with multiple decision support system at the different location and different organization levels.

Decision support system for organizational decision, which may be the task organizing network simulation system, requires information such as the current status of assets, the characteristics of each asset, the geographical condition which will affect the usage of these assets, the communications capacity of alternative

organization network, etc. The type of decision support systems for organizational decision tends to be the network simulation system of the chain of command, and information resource allocation and exchange protocol type. This type of decision has less significance in time parameter, and requires some statistical analysis by human decision makers more than the other types of decision do. The information base for this decision type is static and unique to the organization because no decisions takes place related to this decision at different organization and the assigned assets different to each organization. So the information base and human computer interaction (HCI) is highly dependent on the capability of operators. Thus the effectiveness of C^3 system for organizational decision type requires the training of battle managers to use the system relatively more than the other cases.

Decision support system for informational decision, which may be the situation assessment system, requires information such as the identification of moving objects, the intention of the objects, the problem solving pattern of the Red Force commanders, etc. This type of decision has a significant time parameter and the information base must be updated in real time base. So decision support systems for informational decision type may be executive support system such as expert system for identification, AI system to figure out the object's intention. The quality of this type of decisions depends on the output of the other informational decision system and cause a series of decisions in a chain reaction such as the operational decisions. So the information base for this decision support system must be in the form of decision oriented information. The decision oriented information base is designed for a specific decision and scripted out of the raw data with the probability of accuracy and the range of description which is discussed in a previous section. This information base is updated in real time. So an information base management system, which has expanded functions over the data base management system, is

required including the rules and knowledge for expert systems. The interaction ratio of human decision makers is reduced but the role of confirmation by human decision makers must be considered in designing the executive system.

Decision support systems for an operational decision, which may be a planning system of the courses of action or a weapon resource allocation system with its utility values, requires information such as the characteristics of the threat objects, the available force assets under the decision making system's authority (command), the availability of supporting assets and its coordination complexity, the responsibility area by the threat pressure, etc. The main function of decision support system for operational decision type may be the weapons allocation system. So an information base management system must update the information base out of the raw data with the probability and the description range in same matter of the case of informational decision type including the engagement rules, the strategy, the commander's way of problem solving. This type of decision support system can be implemented by the AI technology or expert system. But the role of human decision makers is most significant among three types of decision because it is a direction of fire distribution. So all decisions by a full rate computerized decision making system must be reviewed by human decision makers except just a routine computing algorithm. An alternative way is that the human decision maker interact with the partial decision making system (decision support system) in the required transition stages of decision making process continuously. This interaction must be in real time, for the operational decision is in real time basis. So the graphical display system for the commander is the key design parameter in interaction with the decision support system in this case. Also all decisions must be compared in a certain basis such as all decisions for a specific responsibility area (V) or a threat pressure (P).

E. TEST AND EVALUATION

1. Approach of Evaluation

The evaluation of C^2 systems can be approached from three fundamental perspectives: performance of system components, or subsystems; effectiveness of the total C^2 system; and the contribution of the system to overall force effectiveness [Ref. 25:p. 162, quoted from Snyder, 1988]. These three perspectives are divisioned corresponding to its level of boundary and measured by the two basic measures, which are measures of performance (MOPs) and measures of effectiveness (MOEs). The relationships between the system boundary and the measures are shown in Figure 4.12 [Ref. 54:p. 109]. MOPs measure the technical capability of the C^3 subsystem, and MOEs measure the total effectiveness of the C^3 system itself. In addition, the contribution of C^3 system out of the system boundary to the environment are measured by the measures of force effectiveness (MOFEs), and the measures of policy effectiveness (MOPEs).

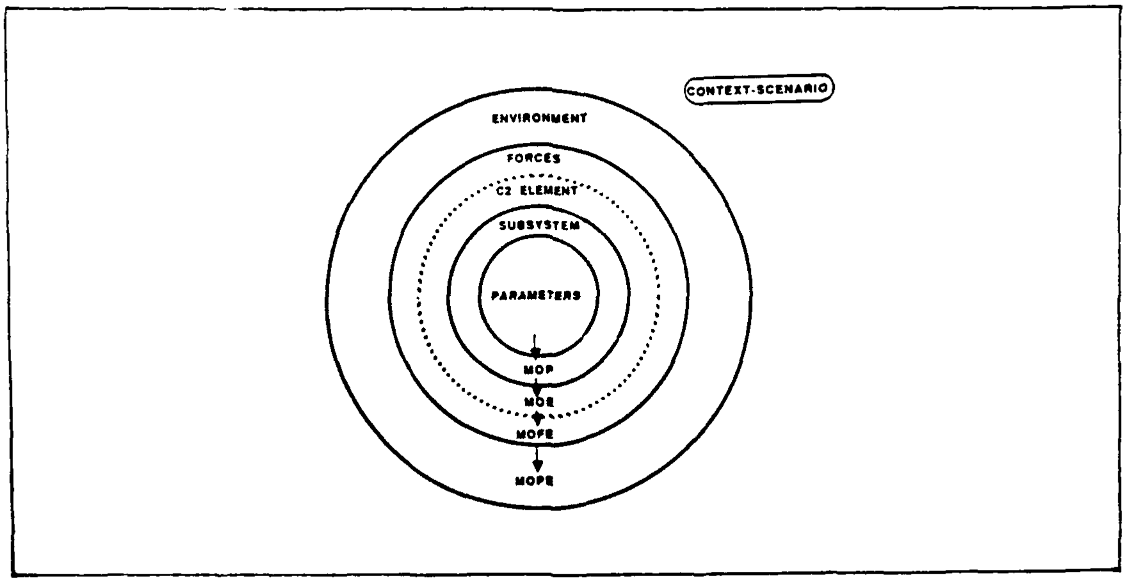


Figure 4.12 System Boundary

The main purpose of the C^3 system is to support the decision making in each level of command and provide the capacity to control the force organization. So the technical support provided by the C^3 system will be measured by the quality of the decisions out of the C^3 system and the effect of the control network. So the criteria to be measured as the basis are the accuracy of information, the timeliness of information arrival or decision making, and task processing rate in a node.

If the criteria of MOPs is not matched to the mission requirements such as the requirement of the particular human decision processes and the required output of C^3 system at a given command level, the capability of C^3 subsystem must be upgraded such as the message transmittal rate, communications capacity, computing rate of computer hardware, the protocol, and the alternative network, in order to increase the system effectiveness. For example, if the information provided by the C^3 system I_s is less than the information demand I_d, then the types of sensor (T), the number of sensors (N), the performance of information processing (P), and the interrelation network among the information processing system must be reviewed:

If $I_s < I_d$

then

functions f, g, and h must be upgraded

because

$$I_S^{(i)} = f^{(i)}(T, N, P) + g\left[\sum_{j=i+1}^{n} I_S^{(j)} \right] + h\left[\sum_{j=1}^{i-1} I_S^{(j)} \right]$$

On the other hand, if the response time T_r is longer than the available time T_p, the weight of some transition stages will be set close to zero, that is to disregard those intermediate transition stages, or the human decision processing time in that nodes as well as the computing rate of hardware must be reviewed, because the MOP of C^3 system is a union of C^2 process and C^3 physical component MOPs [Ref. 55:p. 881].

If $T_r > T_p$

then

set weight rate $w_i = 0$ or

upgrade the hardware computing rate or the human decision processing rate

because

$$T = \sum_{i=1}^{n} \left[T_o^{(i)} + T_d^{(i)} \right] + T_e^{(1)}$$

$$T_r \leqq \sum_{i=1}^{n} \left[T_p - t_m\right] \cdot W_o^{(i)} + \sum_{i=1}^{n} \left[T_p - t_m\right] \cdot W_d^{(i)} + t_m$$

MOEs are quantities that result from the comparison of the system MOPs to the mission requirements. They reflect the extent to which the system meets the requirements. To evaluate the MOEs, it is necessary to go outside the boundary and consider the environment. [Ref. 56:p. 4] The environment outside the system is the operational environment, which is the mission performance standards of weapon systems where the functions of C^3 system is performed. So MOFEs is a MOE in which a standard of mission performance has been explicitly included. [Ref. 56:p. 5]

The total measure of force effectiveness is then the MOPs of C^3 system plus the MOPs of the weapon systems. The MOPs of C^3 system is divided into the MOPs of human C^2 process and the MOPs of the C^3 physical components because the C^3 system is basically people intensive, whereas the weapon systems is only hardware intensive. This evaluation approach is shown in Figure 4.13. [Ref. 56:p. 5]

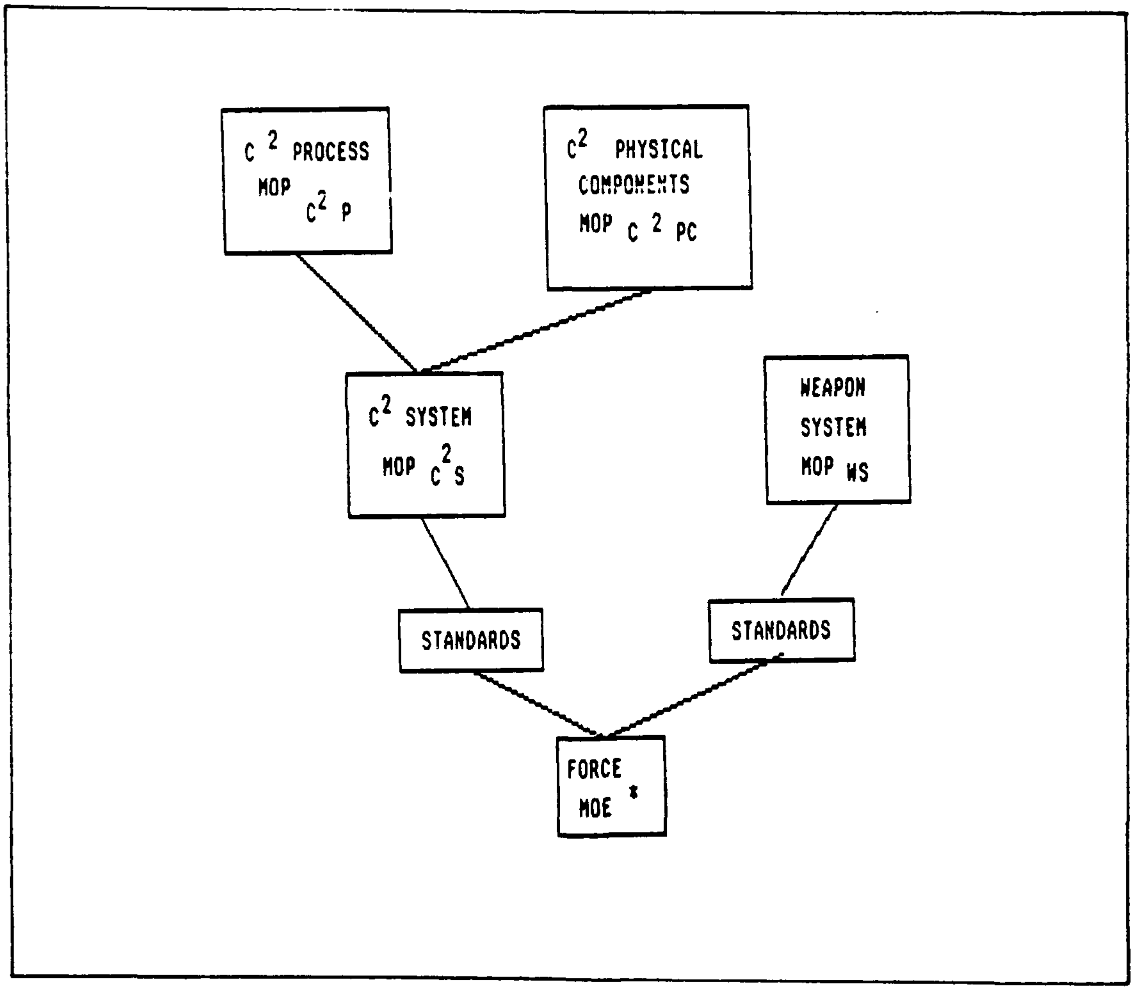


Figure 4.13 C^3 Evaluation Approach

2. Methodologies of C^3 System Evaluation

Currently, there are three major system evaluation methodologies: headquarters effectiveness assessment tool (HEAT), modular command and control evaluation structure (MCES), and system effectiveness analysis (SEA).

HEAT is a data collection scheme based on the cybernetic theory of C^3 (which divides C^3 into cyclic activities – sense, assess, etc.) [Ref. 57:p. 6]. The MCES is a decision maker driven analysis tool. The level of decision as well as the mission and the specific nature of the decisions are taken into account. [Ref. 54:p. 106] The MCES methodology provides a logical and orderly structure that guides the analyst through the process of formulating the measure of effectiveness that are appropriate for the problem in question. SEA, however, focuses on the quantitative aspects of obtaining and evaluating measures of effectiveness. [Ref. 56:p. 6]

SEA is conducted in seven steps. The seven steps of the methodology and their interrelationships are shown schematically in Figure 4.14 [Ref. 58:pp. 3–4]. The SEA methodology is described by Levis analyzing the relationships with the MCES methodology [Ref. 56:pp. 4–11]:

> The first step in SEA consists of defining the system, the environment, and the context, followed by the selection of the parameters that influence the system MOPs. This step is a specific implementation of Modules 1 to 4 in MCES.
>
> In the second step, the analogous procedure is carried out for the mission. Parameters of mission are defined that are consistent with the environment of the context.
>
> The third step consists of defining MOPs for the system that characterize the properties that are of interest in the analysis. The MOPs are expressed as functions of the parameters such as
>
> $$MOP_i = f_i\ (x_1,\ldots,x_k)$$
>
> The fourth step consists of selecting the models that map the mission parameters y_i into the requirements:
>
> $$R_m = f_m\ (y_1,\ldots,y_n).$$

The fifth step consists of transforming the system measures and mission requirements into a set of commensurate attributes defined on a common attributes space; the system MOP space or the mission requirements space.

The step six constructs system locus and mission requirements locus. The measures of performance for the system are functions of the system parameters. System locus is a set of values that MOPs take from the MOP space in allowable range of the parameter x group. Mission locus is the set of values that satisfy the mission requirements.

The seventh step consists of procedures for comparing the system's MOPs and mission's requirements through the geometric properties of two loci.

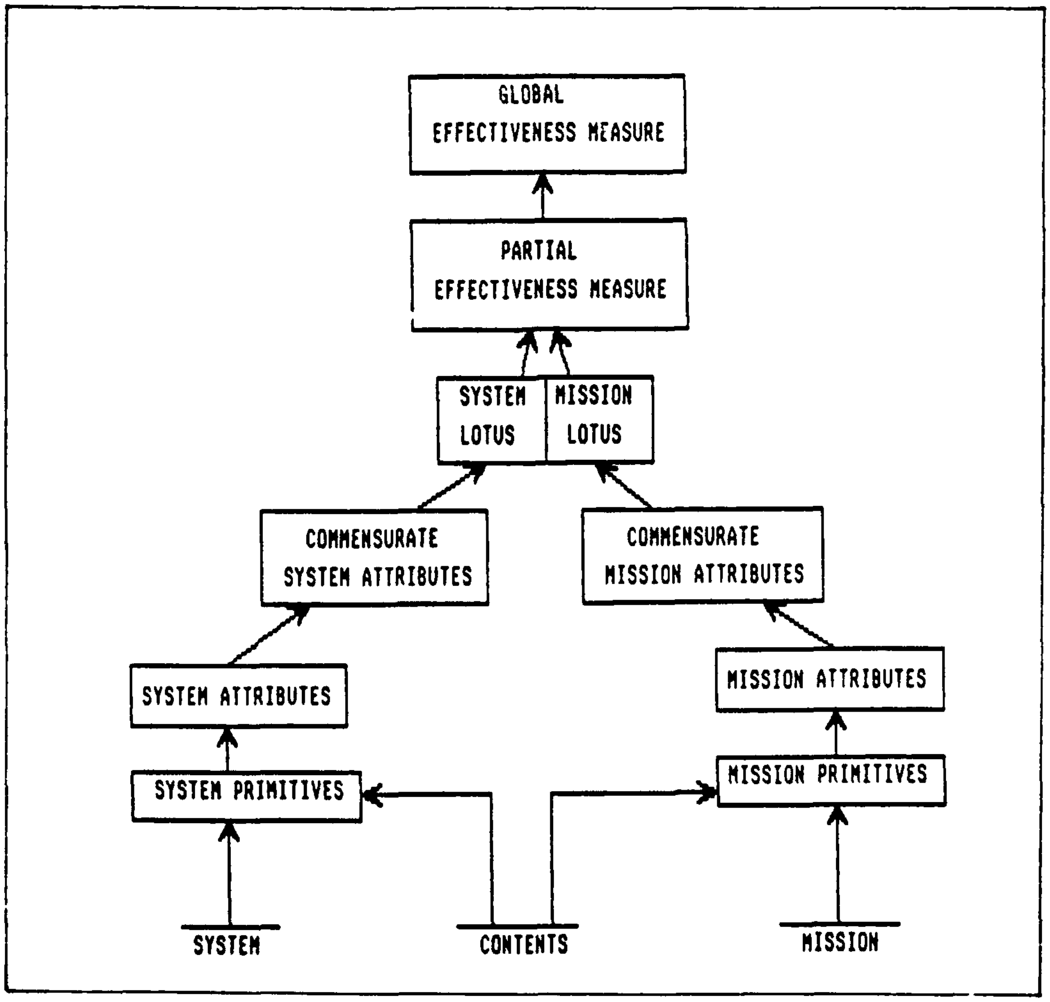


Figure 4.14 The Methodology for C^3 System Effectiveness Analysis

The MCES approach was conceived and developed through a series of workshops commencing with the Measures of Effectiveness for C^3 Evaluation Symposium hosted by the MITRE Corporation, Bedford, Massachusetts, in early 1984. The MCES consists of seven steps (Figure 4.15) [Ref. 56:pp. 5–6].

> In the first module, the decision makers requirements are expressed in the form of a problem statement consisting of a set of objectives and the associated assumptions.
>
> In the second module, the problem statement is used to bound the problem, i.e., specify the boundaries of the system to be analyzed. The result is the identification of the system components and their interconnection.
>
> In the third module, the particular command and control process is described. The result is the specification of the set of functions such as "sense", "assess", "generate", "select", and "direct".
>
> The allocation of the functions derived in module three to the components and structure is carried out in module four. Thus, in the first four steps, the complete formulation of the problem is achieved.
>
> The next three modules constitute the "solution" to the problem. In module five, the various measures that are relevant for the problem in question are specified: MOPs, MOEs, and, if appropriate, MOFEs or MOPEs. Such measures as survivability, reliability, and interoperability are typical examples of MOPs. However, these measures represent general concepts; there is need for problem – specific variables that are measurable and can represent these MOPs. The values of these variables should be computable from data generated by the system. Finally, in module seven, the aggregation of MOEs is carried out.

The MCES is a set of procedures that permits the analyst to evaluate problems. The heart of this methodology concerns what to measure and how to evaluate (Figure 4.16) and the key issue is properly matching the analytic objective to the appropriate set of measures [Ref. 54:pp. 107–108]. The three last modules of MCES can be implemented by the methodology of SEA because the SEA focuses on the "solution". In other words, the steps of the SEA can be embedded in MCES and especially in the last three modules. [Ref.56:p. 6]

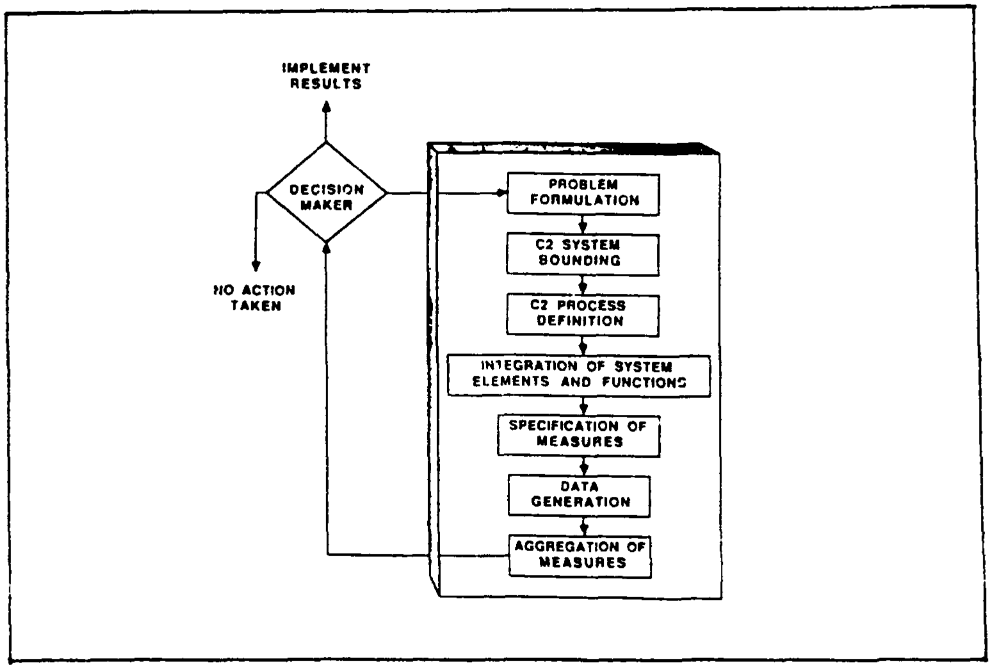


Figure 4.15 The MCES Approach

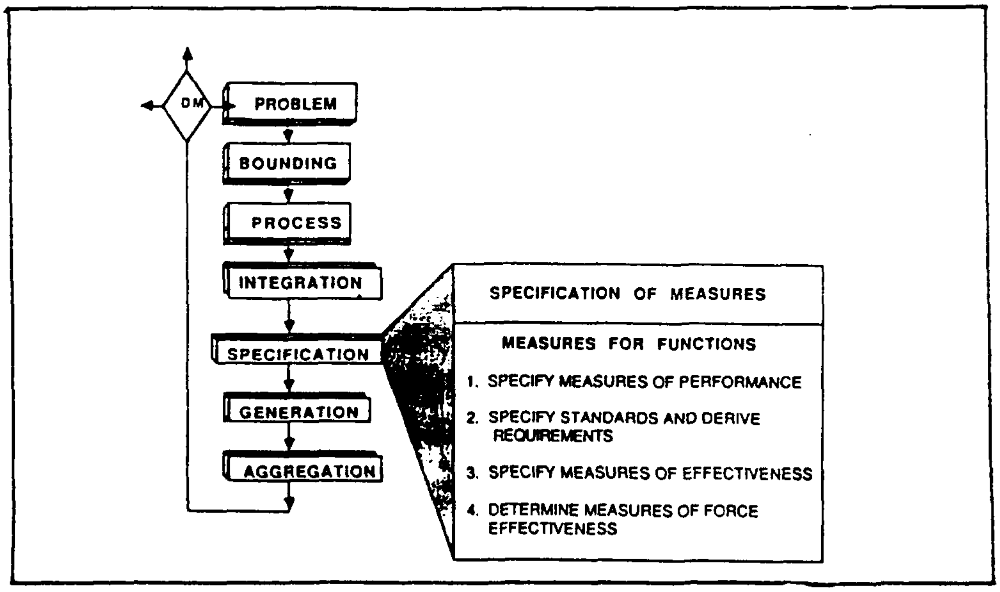


Figure 4.16 Specification of Measures

3. C^3 Effectiveness Analysis

In Chapter I, the force power driver was defined as the function of performance level of each C^3 component (P) and inertia power α:

$$\text{Power Driver} = f[P_{(1)}, P_{(2)}, \ldots, P_{(n)}, \alpha]$$

The term with $P_{(i)}$ is directly from the capability of each component and α is from the potential capability of subordinate commanders which comes out of their experience and the training level. How can these capabilities be measured?

Assume that a commander has three assets available to commit in an operation and one target, and there are simply four variables as C^3 components: command, control, communications, and intelligence. The capability of the computer component of C^4I^2 will be inserted in the intelligence part as the time factor and the accuracy of the information because the advantage of computer are the fast computing speed and the accuracy of calculation. The interoperability component may be out of the C^3 components boundary because it represents the interaction between C^3 systems. Within an operation of one C^3 system, it will be inserted in the command and control part as the directives or orders.

For the easiness of the tactical C^3 system effectiveness analysis, for example, let the intelligence component provide the information about the status of both Red and Blue Forces, especially the location of the target, and the command and control components assign the tasks based on the intelligence. Then the command and control process (weapon resource allocation) in this simple case may be represented by Figure 4.17.

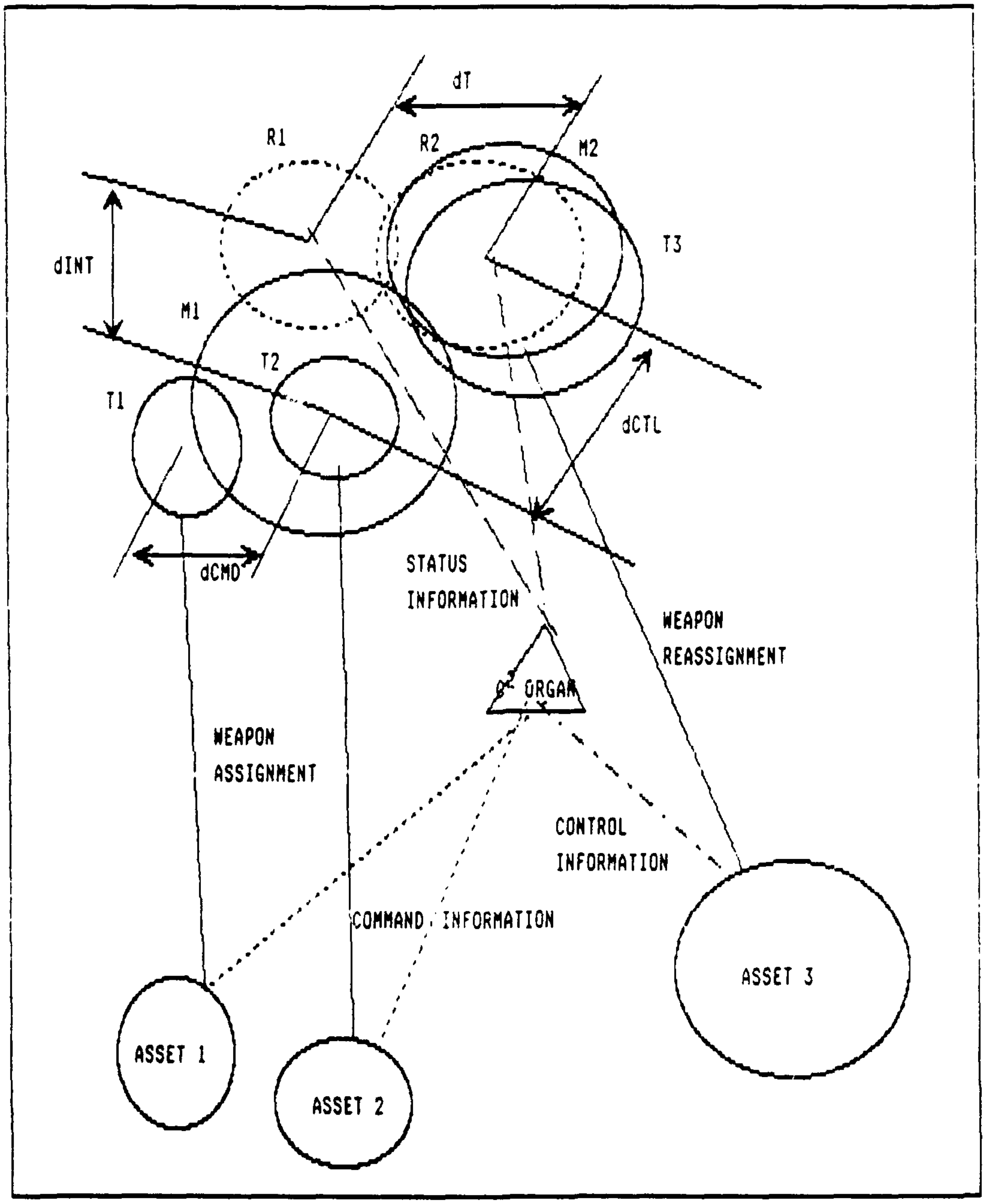


Figure 4.17 Tactical Command and Control Process: An Example

Let the real position of a target be R1 at time t, R2 at time $(t + \Delta t)$, and the reported position of the target be M1 at time t, M2 at time $(t + \Delta t)$. And assume that the commander assigns the tasks T1 to asset 1 and T2 to asset 2, also, after time Δt he recognized that the target moved to the position R2 and the size of target (actually the military pressure or force power) turned out to be larger than the old intelligence part provided. Then the commander will reassign the task to asset 3 which destruction power matches the size of the target power.

In this scenario, the performance of the C^3 components may be measured by the following method. The capability of intelligence corresponds to the deviation (dINT) between R1 and M1. The ideal case is that the location and the size of both circles are the same. So the performance of intelligence may be

$$P_{int} = \frac{(R1 \cap M1)}{M1}.$$

In this case, the performance of intelligence has some amount of value as shown in the figure above.

The capability of command corresponds to the deviation (dCMD) between M1 and (T1 + T2). The ideal case is that the location of all T1, T2, and M1 are the same and the total size of both T1 and T2, which are identical to asset 1 and asset 2 each, is same as the size of M1. The size means the military pressure, too. Then the performance of command may be

$$P_{cmd} = \frac{(T1 \cup T2) \cap M1}{(T1 \cup T2)}.$$

In this case, the performance of command has some amount of value, but for the forces it has no effect due to the misinformation.

The capability of control is to catch the deviation (dCTL) between (T1 + T2) and R2 at time ($t + \Delta t$) and reassign the task. The ideal case is that (1) the location of all T1, T2, and M2 are the same and the total size of both T1 and T2 is identical to M2 and R2, or (2) the location of both T3 and M2 are the same and the size of T3, which is identical to the asset 3, is same as the size of M2 and R2. So the performance of control may be

$$P_{ctl} = \frac{[(T1 \cup T2) \cap M2] \cap R2}{(T1 \cup T2)} \cup \frac{(T3 \cap M2 \cap R2)}{T3}$$

If there is no reassignment and no adjustment of task T1 and T2 in this case, the performance of control is zero.

The capability of communications is to transmit the information signal (status and command or control information) without distortion of the information in time. The ideal case is that there is no change after time Δt, the interval time between the target is detected in sensor node and the mission is planned in C^2 organ node, and the interval between the mission is planned and the mission is received and initiated, in the status information (target location in this case), and there is no difference between command information and status information. It means that the mission is initiated simultaneously when the target is detected. But it is impossible even though the C^3 system is in real–time operation. So the alternative way to measure is to check the change of location and the difference of both information contents after time Δt. Let the time delay from sensor to C^2 organ be t_1, and the time delay from C^2 organ to asset (subordinate unit), t_2. The performance of

communications may be the multiplicative product of performance of communications during t_1 and t_2 because a failure in either link cuts the sequential process of command and control. The performance of communications at t_1 may be the difference of status information between at time t in sensor node and at time t + t_1 in C^2 organ node. That is

$$P_{comm}(\text{at } t_1 \text{ link}) = P_{int}(\text{at } t) - P_{int}(\text{at } t_1)$$

The performance of communications at t_2 may be the distortion of command information between at time (t + t1) in C^2 organ and at time $(t + t_1 + t_2)$ in subordinate units. That is

$$P_{comm}(\text{at t2 link}) = P_{cmd}(\text{at } t+t_1) - P_{cmd}(\text{at } t+t_1+t_2).$$

However, after time Δt, same kind of communications exists with factor of Δt instead of t_2, that is, the control link:

$$P_{comm}(\text{at } t+\Delta t) = P_{ctl}(\text{at } t) - P_{ctl}(\text{at } t+\Delta t).$$

So the total communications capability may be

$$P_{comm} = [P_{comm}(\text{at } t_1 \text{ link}) \cap P_{commu}(\text{at t2 link})] \cup [P_{comm}(\text{at } t_1' \text{ link}) \cap P_{comm}(\text{at } t+\Delta t)]$$

where t_1' link is the time when the commander recognized the misinformation.

From the discussion above, the C^3 effectiveness function may be represented by the next form with multiplicative and additive charateristics.

$$\text{Power Driver} = P_{int} \cdot P_{cmd} \cdot P_{comm} + P_{int} \cdot P_{ctl} \cdot P_{comm} + \alpha.$$

If there is no communication link, intelligence (status information) is not provided to the C^2 organ, and mission or task (command and control information) is not assigned (command) or reassigned (control) to the subordinate units. The value of each intelligence and command or control is not added directly for force operation, so the total value of C^3 system becomes zero. The reason that the force conducts its mission is from the self maintenance power of the subordinate units when they are facing a hostile situation. It is a inertia power based on the higher commander's past pattern and the subordinate commander's experience.

Also if there is no intelligence, the task assignment (command) or reassignment (control) may be possible but arbitrary. So it is not direct effect from the commanding force's C^3 system. It is from the perception of the commander based on the commander's ability.

If there is no command and control, the value of intelligence and communications performance is not useful for the subordinate units. It is rather to effect some negative effectiveness. The subordinate commander will think there is some undesired situation at the higher command and may feel some fear which decreases the motivation.

V. A C^3I SYSTEM DEVELOPMENT AND ACQUISITION PROCEDURE: CASE STUDIES

A. REQUIREMENTS ANALYSIS

1. Decision Needs Requirements Analysis

The general acquisition procedure of a weapon system consists of various phases such as Program Initiation Phase, Concept Exploration/Definition Phase, Concept Demonstration and Validation (D&V) Phase, Full–Scale Engineering Development (FSED) Phase, Full Rate Production/Initial Deployment Phase, and Operations Support Phase [Ref. 59]. The first phase initiates with the requirements analysis. The typical requirements to be analyzed are the mission need requirements. For the case of C^3 system development, the mission requirements drive decision requirements which are the key design parameters in C^3 system design because the output of the C^3 system determines the quality of decisions at a command. Adopting the decision–oriented system design approach by Metersky [Ref. 55], these decision requirements are expanded into three sub–detailed requirements: information requirements of organization, software requirements, and hardware requirements. And these three requirements are transformed into decision augmentation specification, software specification, and hardware specification through various intermediate steps. These steps are shown in Figure 5.1 [Ref. 55:p. 888].

The decision requirement in a unified forces level must be developed under the mission requirements of the unified forces level. The system context in a unified forces level, thus, must be analyzed first. When a conflict occurs initially,

the role of the unified force's commander (initial mission) is to provide an assessed report about the situation to the President. Once they receive a direction to respond to the conflict, the follow–on mission is to accomplish the direction. So the decision types in the unified forces level are a decision about the early warning to the President and its subordinate command, and a decision about the response, that is, a broad action exchange type selection with the conflict and the control.

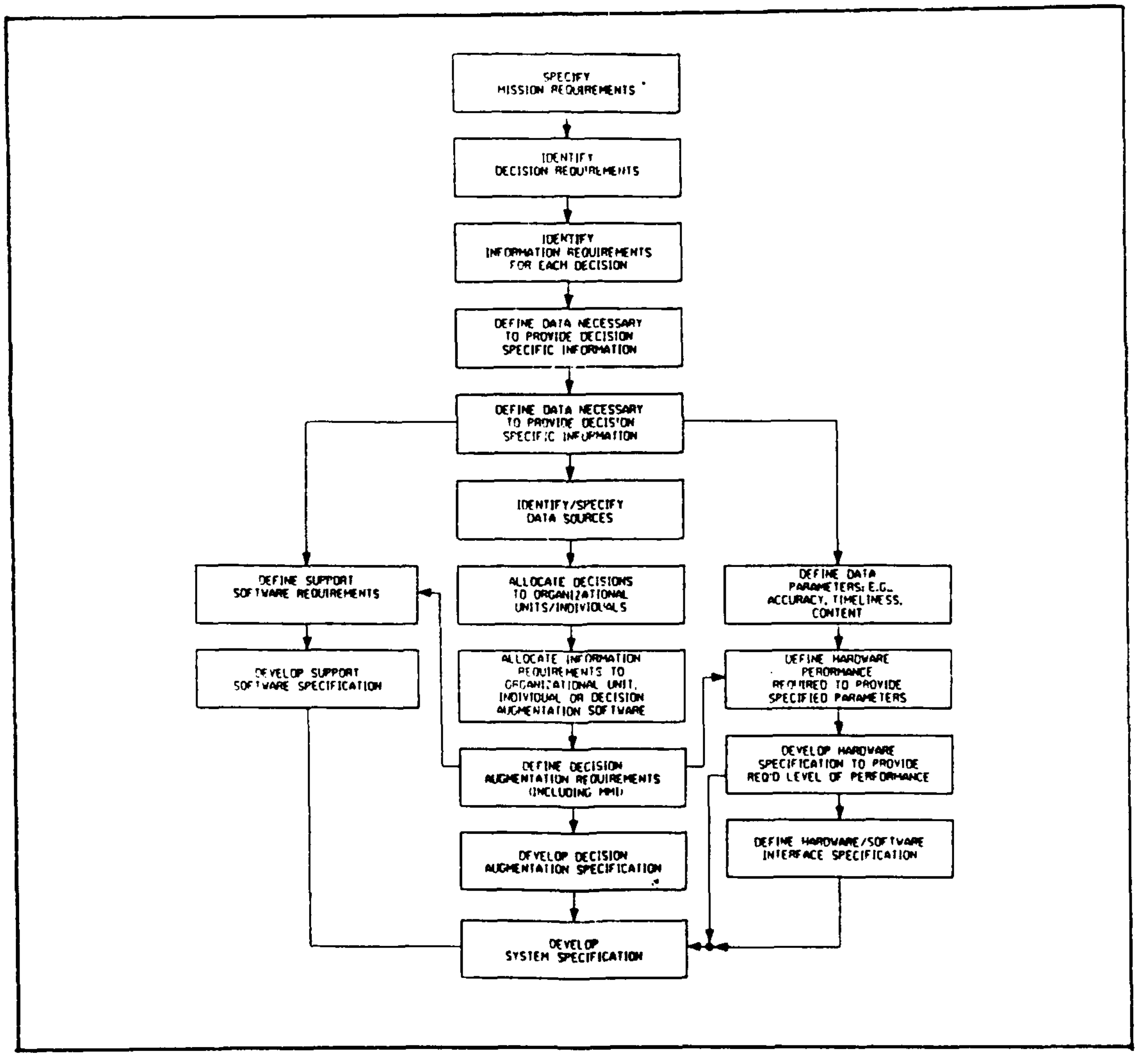


Figure 5.1 Decision–Oriented System Design Approach

In the unified forces level, the decision is made in the central stage of the command and control transformation process through the command and control time line and the decision type is at the top battle management level. This phenomenon is shown with the graph of Figure 5.2 [Ref. 60:p. 3]. So the decision requirements will be the information requirements for the early warning and the response type, the information allocation requirements to the subordinate units for the early warning, the task allocation requirements to the organizational decision making group such as the Navy, Air Force, and Army Components headquarters for the response type, and software/hardware requirements for the two major decision types to be able to meet the required quality of the decisions.

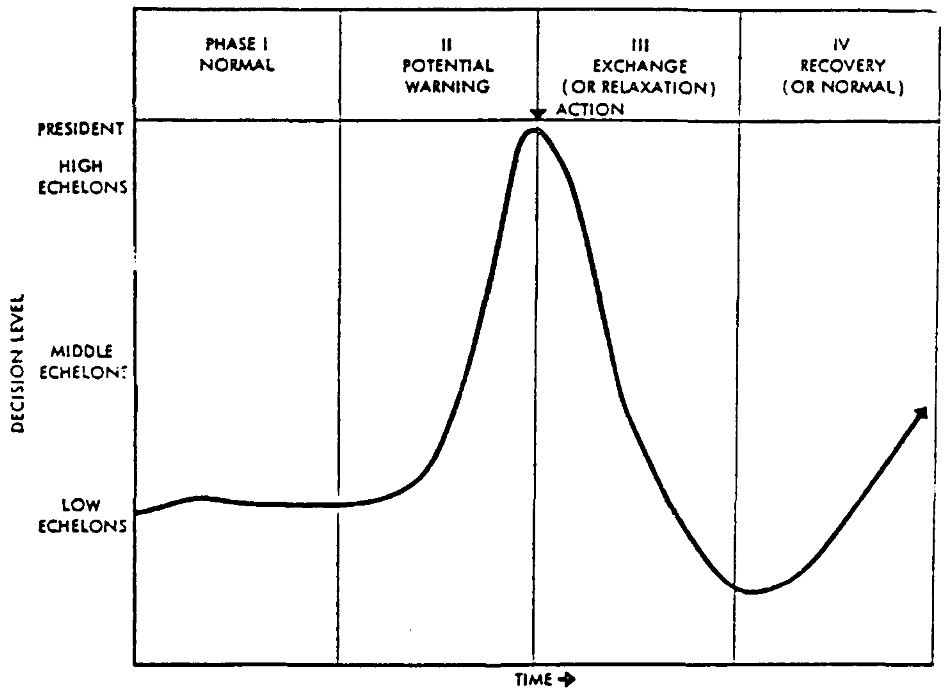


Figure 5.2 The Decision Making Level and the Time Plot

2. Requirements Management

Requirements are proposed by the operations people, while systems are designed by technical engineers or designers. The operations people know what they need to accomplish but do not understand the technology well enough to know what they could accomplish given a modern and affordable system; the technologists understand what could be built but don't understand the operations well enough to define what should be built. So together with requirements and system design, operations concepts are developed in parallel based on policy, doctrine and the performance of the new systems. [Ref. 61:p. 15]

To accomplish these three works successfully, the users must be involved in the system acquisition together with the developers. The user/developer team, then, analyzes the missions, operations environment, the required operational capability (ROC), for example, in order to manage the requirements. If good operational people and technical systems people get together under a set of well structured rules, they could come out with requirements and affordable systems to meet those requirements based on system analysis, system costing and significant trade–offs. This team must regulate the desired changes in requirements which may come up in the life of the program. The types of questions this team should be forced to answer are: [Ref. 61:p. 20]

- What is the object of the exercise?
- What military job(s) is the system going to support?
- What will be the improvement in military effectiveness if the system is built?
- What is the cost performance curve? How does it affect the system requirements?
- What are the absolute minimum requirements?
- Have necessary/possible improvements in the way the user does things (doctrine, procedure, etc.) been taken into account in formulating the requirements?

- Can we get operational improvements without requiring new systems?
- Are we pushing the state–of–the–art?
- How do the requirements and improvements impact on other systems and actions; How are they impacted by other systems and actions?
- How are we going to use and operate the resulting system?
- In order to do a good gob of requirements definition, do we need an operational test bed? A developmental test bed? Subsystem test bed?
- What are the requirements priorities? Have they been rigorously rank ordered?

3. Subsystem Requirements

a. Command and Control Requirements

The establishment of the US military departments, services, and the combatant commands set up two distinct chains of command. The first chain of command is the operational channel of authority assigned to combatant commands. The second chain of command is the service channel of authority for purpose other than operational direction of combatant forces [Ref. 63:p. 56]. The command and control requirements of unified forces is generated by the unified operations and joint actions. JCS PUB 2 describes the requirements of command and control as follows:

> Unified operations and joint actions generate certain requirements. These include integrating efforts toward common objectives, planning and conducting operations under unified direction, developing doctrine for preparing and training specific type of combat operations, and delineating responsibilities and developing doctrine for unified operations. [Ref. 63:p. 96, quoted from JCS Pub 2, para 10104]

The commander of the unified forces is authorized to exercise his assigned operational command. This operational command is exercised through more than one service component commanders–the land, naval, and air components. According to JCS Publication 2, the unified commander is authorized to:

- Plan for, deploy, direct, control, and coordinate the action of assigned forces.
- Conduct joint exercises.
- Exercise direct authority for logistics within his command.
- Exercise direct authority over all elements of his command.
- Establish plans, policy, and overall intelligence activities of his command.
- Participate in the development and acquisition of his command and control system and direct its operation.

The command and control requirements are the key of the architecture of the command and control organization. But one more aspect of command and control requirements is the commander's leadership and the degree of control. The U.S. Army defines military leadership as "... a process by which a commander influences others to accomplish the mission" (FM 22–100, Military Leadership). The leadership then can be represented by the degree of motivation of the subordinates. The motivation and the degree of control required to accomplish a mission is related to its level of command as shown in Figure 5.3 [Ref. 62:p. 33].

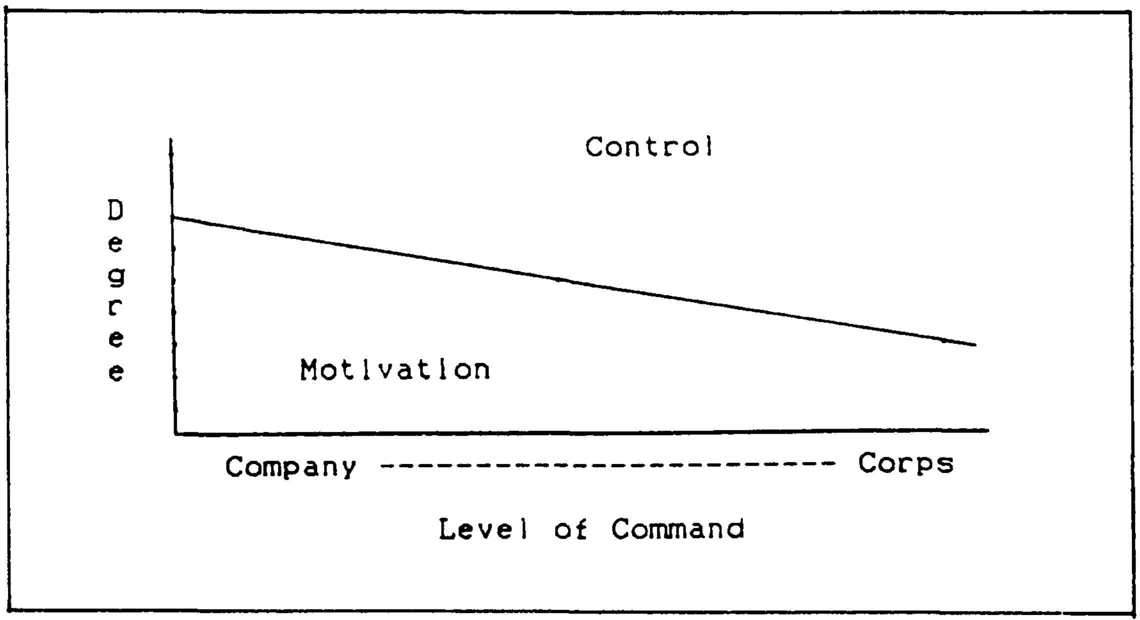


Figure 5.3 Motivation vs. Control

b. Intelligence Support Requirements

The intelligence requirements of a C^3 system in a unified command level follows information requirements corresponding to a specific decision under the uncertainty–time distribution plot of the unified forces. As discussed in the first section of this chapter through Figure 5.2, the role of decisions of the unified commanders are inserted into the middle stage of the total command and control time line from the event detection to response execution. The first one was the early warning task and the other was the planning task for the required response. The next concern is the available time to make decisions for the warning and to develop planning.

The first function of the early warning decision is to monitor the current situation. The intelligence system is the primary resource for monitoring the enemy situation. So the time allocation of each intelligence system is a critical factor in the intelligence support. Intelligence support requirements for the early warning system must include the real or at least near real reporting channel. Thess requirements may disregard the cost curve because the timeliness is the absolute factor for this early warning decision type. In other words, the time delay in early warning makes the benefit of the C^3 system close to zero even the system took cost to exist. To meet this requirement, the C^3 system requires the machine to machine interface module of information among each service individual intelligence system.

For the planning function of the unified forces level, a C^3 system has a little flexible time allocation. Remembering the transformation function of command and control is the weapon resource allocation and its increasing utility, the time allocation is affected by the available weapon resources and the area of responsibility or the area of military pressure. Table 5.1 [Ref. 64:p. 206] shows

one experimental planning time chart with its intelligence support system (RSTA: reconnaissance, surveillance, and target acquisition). In a same matter, the intelligence response time for weapons resources allocation can be estimated.

The intelligence support requirements is set by analyzing the required information quality (accuracy, description diversity, and timeliness) for a specific decision type. One example is shown in Table 5.2 [Ref. 64:p. 204]. When a weapon is assigned to a target in a responsibility area, C^3 system requires some intelligence support corresponding to the allocation type.

Table 5.1 Areas of Interest for Planning

Level	Planning Block (hrs)	Max Effective Range (km)	Areas of Interest	RSTA Support
Division	Next 12	30	*120 km	Corps
Corps	Next 24	30	**240 km	EAC, Nation
Army Group	Next 48	150	***480 km	Nation
AFCENT	Next 96	350	****1920 km	Nation

* 6 hr. road march @ effective 20 kmh
** 12 hr. road march @ effective 20 kmh
*** 24 hr. road march @ effective 20 kmh
**** 48 hr. rail movement @ 40 kmh

Table 5.2 Intelligence Support Requirements: Cases

Range Band	Target	Weapon	Intelligence Support
FLOT to 30 km	Final assembly area, Units moving to Battle	• Tube Artillery • MLRS • Tactical Aircraft (A-7, A-10)	• Intelligence Preparation of the Battlefield to identify assembly areas • Single/multi-source collection system products • High resolution imagery for target location confirmation • Multi-source fusion to support situation assessments and target development
30 to 150 km	Assembly areas, Division march columns, choke points, Halted units	• Tactical Aircraft (F4, F16)	• *Same as FLOT to 30 km, plus:* • Activities in support of penetration of enemy airspace and suppression of enemy air defense. • Near real time target update to aircraft and missile system just prior to launch • Post launch target acquisition or location update during terminal phase of engagement. • High resolution imagery for target tracking • Cross corps situation and target development coordination for fire support to adjacent corps
150 to 350 km	Assembly areas, Choke points, Units in transit of choke point, Halted units	• Tactical Aircraft (Toronado, F111) (Planned F15E)	• Same as 30 to 150 km, without cross-corps support
350 km+	Rail networks	• Strategic Aircraft with conventional stand-off weapons (Planned B-52 with cruise missiles)	• High resolution imagery for target location confirmation

c. Communications Requirements

The concept of modern command and control systems can only be implemented with the availability of a sophisticated communication network. In fact, communication and data transfer are the key factors to effective C^3 system operation and are therefore heavily emphasized in any C^3 system planning. The communication technologies have an extreme range of options to offer the system designer, as seen in Figure 5.4 [Ref. 65:p. 27].

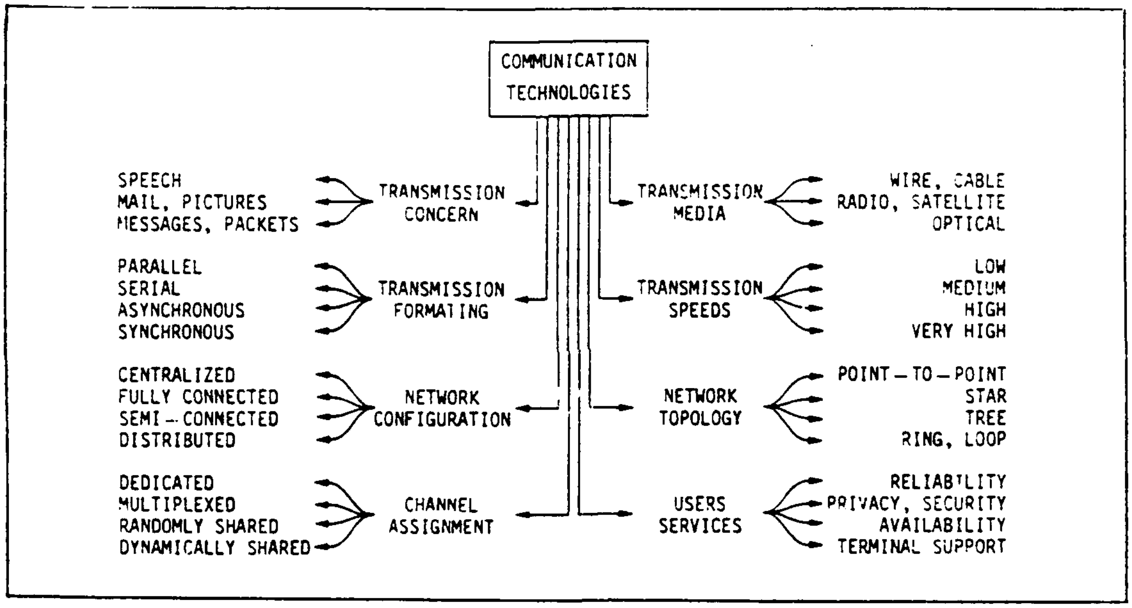


Figure 5.4 The Major Branches of Communication Technology

Effective C^3 system operation also depends upon a well designed communication network. The consideration of communications design in C^3 is the integral performance of C^3 system. For the integral function of a large C^3 system, ISO proposed OSI seven layers for the open system model, which is introduced in Chapter II. But the ISDN (Integrated Services Digital Network) technology is a good candidate for C^3 system networking. All modern information system firms

tend to use this ISDN technology because it can provide interface among all communications equipment involving voice, data, video, etc. The military C^3 system must use the industrial computer and communication technology in order to save the R&D cost and save time of system acquisition. Then the development of the C^3 system can better follow the industrial technology to develop a system for expansion of the system in the future. It supports the interoperability between various systems: compatibility between existing and new system, interconnection among different systems, etc.

Inadequate communication design results in delays in the transmitted data before reaching their destination. One requirement of communication is the communication transmission capacity. The "average traffic rate" is not reasonable for C^3 communications network design because the network will be jammed at the peak traffic time. It can bring the system operation to a standstill. So the designer must consider the maximum random message traffic rate in designing the communications capacity. Whether to use real–time, near real–time, or non real–time communication switching depends on the volume of input message and the time sensitivity of the output which will be used for a information system.

Another consideration of communication requirement is the reliability or survivability of the network. Automation of C^3 system is not always best for combat situation. The designer must consider the failure of system operation such as the Mean Time Between Failure (MTBF) of system components or the destruction of the communications network. Message transmission between machines must have an alternative transmission means. For example, a digital data computer communications network must consider the voice FM communications channel as a backup.

Mobility is another factor of communications requirements. But at the unified forces level, the significance of mobility is less than the lower level. In other words, all possible communications technology can be used in the high command level, while in the infantry division level, the mobility is the key factor for the communications design.

4. Joint Interoperability Requirements

Interoperability is discussed in Chapter II. In the definition of C^3 interoperbility, what really counts in interoperability are the "forces". In the unified level, the forces are of more than one military service. So the jointness is added in the general interoperability requirements in this case. The general interoperability requirements are implemented technically by the compatibility, standardization, and procedure, as discussed in Chapter II.

This C^3 interoperability is achieved by a four step process: identify requirements, develop standards, test and certify against standards, and implement and plan support [Ref. 66:p. 232]. The narrow meaning of interoperability is that communications and data processing equipment must be able to connect and work with one another. But the broad meaning includes people, doctrines and procedures, as well as the equipment [Ref. 67:p. 35]. So identifying the requirements of jointness in the unified level will be done by the study of each service's people, doctrines and procedures as well as the equipments used in each service.

The first step to identify the interoperability requirements is the efforts for "Architecture" and "Assessment" [Ref. 66:p. 232].

An "Interoperability Architecture" by Joint Tactical C^3 Agency (JTC^3A) is a document that:

- identifies C^2 element;
- identifies C^2 system;
- establishes connectivity and information needs;
- identifies supporting communications systems;
- identifies interoperability deficiencies;
- recommends corrections and improvements.

JTC^3A produces two kinds of architectures: Functional Interoperability Architectures and CINC Architectures. The functional interoperability architectures are being developed for each of the major combat functions. These architectures cut across all CINCS/services/agencies and attempt to capture the essentials of the interoperability equation within the functions. On the other hand, CINC interoperability architectures are developed by JTC^3A at the invitation of the CINCs and are tailored for the theater of operation and the forces of that command. They cut across (and are built upon) the functional interoperability architectures and will be "refreshed" as the requirements change over time. [Ref. 66:p. 232]

JTC^3A assessments are in two categories: technical and system. Technology assessments are focused on a specific technology and attempt to identify all the technological issues that affect interoperability. On the other hand, the system assessments are focused on a specific C^2 or communications system and attempt to identify all the technical, procedural and operational issues that affect interoperability. [Ref. 66:p. 232]

The methodology to identify the interoperability requirements deficiencies is the requirements evaluation methodology. One approach to evaluate the interoperability requirements is to check the sequence of information exchange. When initial information is exchanged, it may often lead to a sequence of further data exchanges. Marshall and Greenway expressed this as: [Ref. 68:p. 176]

- Verifying that information exchanged is comprehensible to all participating systems.
- Verifying that the information expected by a system is generated by another system.
- Verifying that the information generated by a system is expected by other systems.
- Detecting any degradation of information when exchanged, and verifying that this is acceptable. This is particularly important where information is relayed through a series of inhomogeneous systems since minor degradation at each system becomes a major degradation from end to end.

B. SYSTEM DESIGN AND ENGINEERING

1. The Framework of C^3 Architecture

The overall C^3 architecture has three types of architecture: organizational architecture, functional architecture, and physical architecture [Ref. 25:p. 128]. An organization has an objective and the C^3 mission to command and control the organization to obtain the objective. The chain of command, generally represented in an organizational chart is the organizational architecture. Now the C^3 mission is decomposed and translated into its operational functions. These functions have their own architectures. Finally, the functions are performed by physical systems such as computer hardware and software or a communications link. Each physical system has its own architecture, too. Examples of physical systems are the command post headquarters facilities for chain of command, and information system, and communication system. In Thornton's C^2 process architecture, the command and control headquarters is represented by the command executive at the center position, and functional perspective of the overall C^3 architecture surrounds the center. It is limited to the conceptual C^2 process over the command and control time line.

The purpose of C^3 architecture is support C^3 planning such as the C^3 master plan and provide the technical framework for subsystem architectures, thus

allowing for development of the communication architecture, the information system architecture, headquarters architecture, air defense architecture, intelligence architecture and so forth [Ref. 69:p. 68]. The development of C^3 architecture begins with the C^3 mission analysis and end up with the design of the physical subsystem architecture. For the actual development of C^3 system, the conceptual architecture of C^2 process by Thornton requires the developmental framework for C^3 architecture. Jacobovits proposed a solution for this requirement with the "C^3 architecture conceptual framework" which is composed of C^3 mission, physical environment, control and flow of information, and representation, interpretation and transformation of information [Ref. 69:p. 68].

The C^3 mission defines the user aspects of the architecture. Complex C^3systems may need analyses to decompose the mission into operational functions. This decomposition will allow the development of a C^3 subarchitecture for each operational function. The physical environment consists of command and control centers, information systems, communications systems and input sources (sensors, messages). The control and flow of information is driven by the operational function and is essential in describing the architecture because it shows the interrelation between each operational function. The representation, interpretation and transformation of information describe the processing aspects of the information as it flows from sources (sensor or message) to sinks (C^2 centers), and the resulting command and control messages that flow in the opposite direction. [Ref. 69:p. 68]

To present the four categories of C^3 architecture framework, Jacobovits [Ref. 69] used information flow diagram methodology consisting of operational functions, nodes, branches and information sources (Figure 5.5) [Ref. 69:p. 71]. The operational functions are generated by the C^3 mission and defined clearly to identify

the type of information and flow of information. For example, the operational function of surveillance subsystem requires the real time technical data for both friendly and enemy identification and, needs to build a broadcasting network to disseminate the surveillance result. The nodes on the diagram are generic processing and control centers and represent the respective processing and control tasks within C^2 organization. Processing encompasses the representation, interpretation and transformation of information aspect of the framework. Control encompasses the control aspect of the control and flow of information. The branches represent the flow aspect of the control and flow of information part of the framework. [Ref. 69:pp. 71–72]

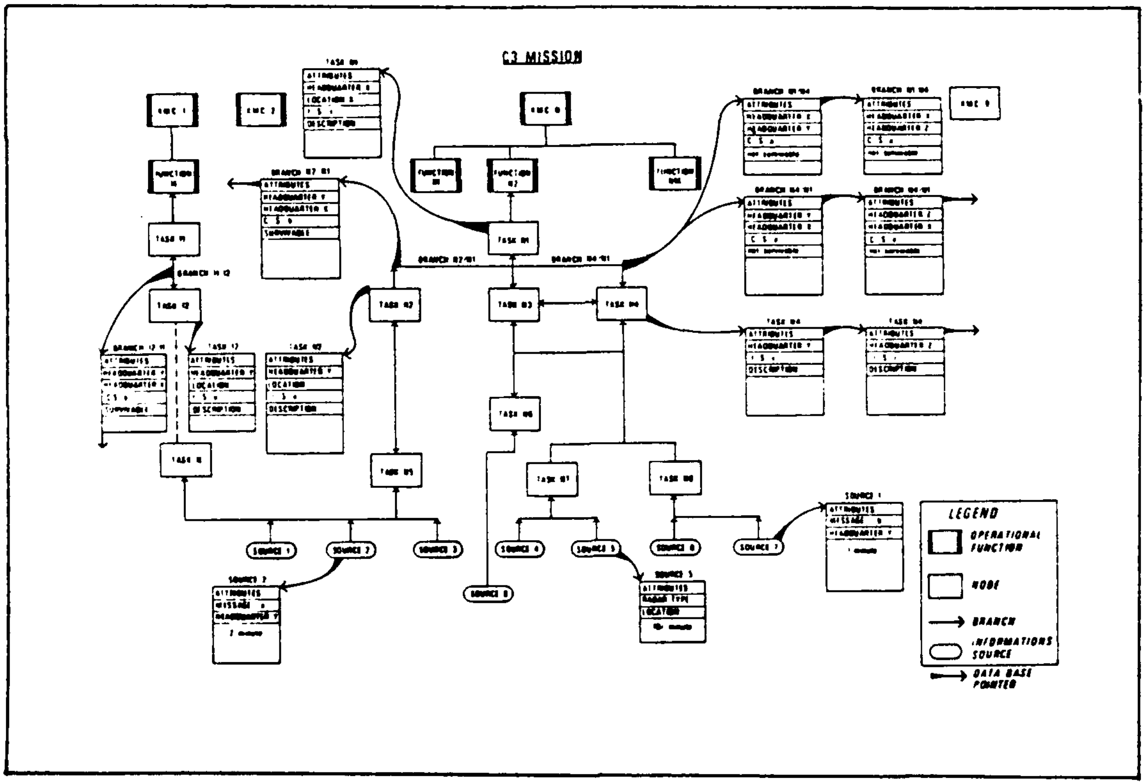


Figure 5.5 C^3 Architecture Conceptual Framework

2. C^2 Organization Architecture

a. Unified Command Structure

The unified command structure is the integration of forces provided by the military departments for combatant commands, and the underlying principle of unified operations is the principle of unity of effort. JCS Pub 2 defines unity of effort in the following manner:

> The concept of the US military establishment as an efficient team of land, naval, and air forces is based on the principle that effective utilization of the military power of the nation requires that the efforts of separate military services be closely integrated. .... Unity of effort among service forces assigned to unified or specified commands is achieved by exercise of operational command..... [JCS PUB 2]

There are two principles that must be applied to achieve the full potential of the unified combatant structure. These are the principles of maximum integration and the principle of full utilization of forces. Maximum integration refers to the practicable integration of policies and procedures to "produce an effective, economical, and harmonious organization which will insure the national security". The principle of full utilization of forces states that each service's unique capabilities must be exploited to their full potential to achieve the effective attainment of overall unified objectives. [Ref. 63:pp. 59–60]

The principles and doctrine above provide the framework to set up a command structure to support the unified operations of the armed forces. This structure must be designed to insure the effective coordination of the forces to accomplish the assigned mission: [Ref. 63:p. 60]

> In determining the most effective method,... consideration shall be given first to the mission to be accomplished, and then to the capabilities and functions of the services involved, the geographic location and nature of the contemplated operations...and capabilities of US and enemy forces.

The current US unified command structure consists of operational command authority and service command authority (Figure 5.6) [Ref. 63:p. 173]. The overall commander personally exercises operational command. The unified commander will not act as the commander of any subordinate or component command unless specifically authorized by establishing authority. He exercises operational control through the commanders of subordinate commands or component commands [Ref. 63:p. 61]. The role of JCS is to advise the NCA to command the unified or specified commands. They do not command the unified commands directly.

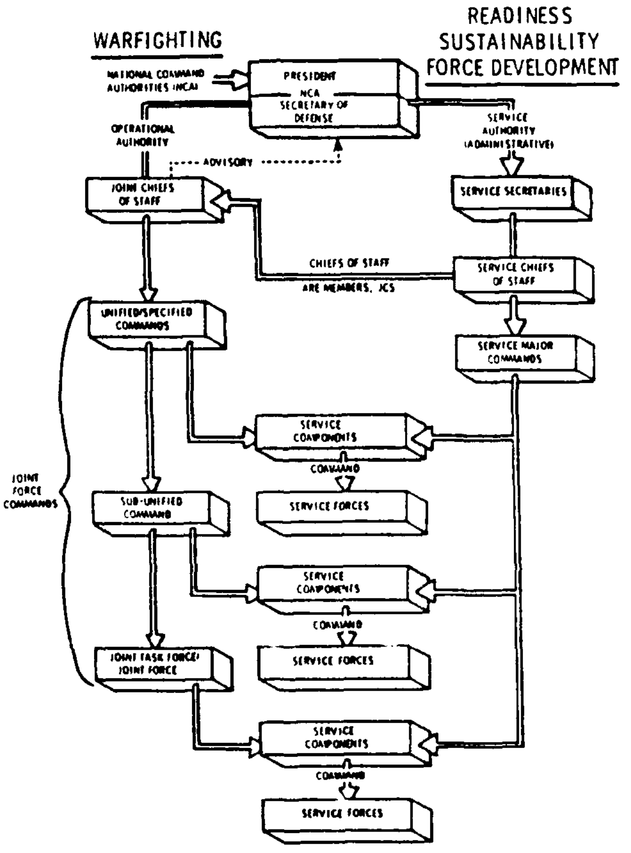


Figure 5.6 The Unified Command Structure [Ref. 63:p. 173]

The subordinate unified or service component command is commanded by the senior officer of that service assigned to the unified command. These subordinate or component commanders exercise operational control over the respective forces and report or "communicate directly with their respective chiefs of services on matters which are the responsibility of the military departments and services." This dual authority of the component commander is derived from the National Command Authority (NCA) and has both service administrative and unified operational authority. [Ref. 63:p. 61]

No matter the type of command (operational or service authority), the command and control process in the chain of command of the unified forces is conducted by the physical C^3 system. Both operational command and service command authority will be characterized by the type of information over the chain of command. Thus the chain of command architecture may be represented by the information exchange network.

b. Future Chain of Command

Information support to the commander's situation assessment is currently generated mostly at the lower levels and flows upward toward the higher echelons, along with associated requests for support. In response, orders flow down to the lower echelons. At the lower echelons, the time available for planning is generally shorter and the level of planning more detailed than at the higher echelons. Also several echelons are involved in compressing and replaying reports, as well as expanding and relaying orders. Much information is exchanged via messages which are manually prepared, distributed, and analyzed. Therefore, the overall response times can be quite long relative to the expected pace of future battles. [Ref. 70:p. 146]

For greater interaction between information systems and the command and control process in the future, each echelon must speed up the operations or need to be informed simultaneously to reduce time delays. Some of these information systems would also provide automated aids to assessment and planning [Ref. 70:p. 146].

In Chapter IV, the alternative methodology for this issue was discussed already, but for the chain of command, Signori and Cheilek suggested the future command and control process with comparison of the current chain of command (Figure 5.7a and 5.7b) [Ref. 70:pp. 147–148]. According to his opinion, the improved sensor system and improved message handling (e.g., preparation, storage, and retrieval) and exchange (e.g., wide–area, jam–resistant communications capability) at each level of echelon reduce time delays of the response. Improved sensor systems give commanders at all echelons some ability to anticipate requests for support, and planned improvements speed up the operations at each echelon. [Ref. 70:p. 146]

The future command and control process shows two types of information exchange links. One is the formal links that provide the message exchange link for orders and reports; the other is the information source exchange links among the sensors and information systems. The first may be called the formal chain of command and the other may be called the virtual chain of command.

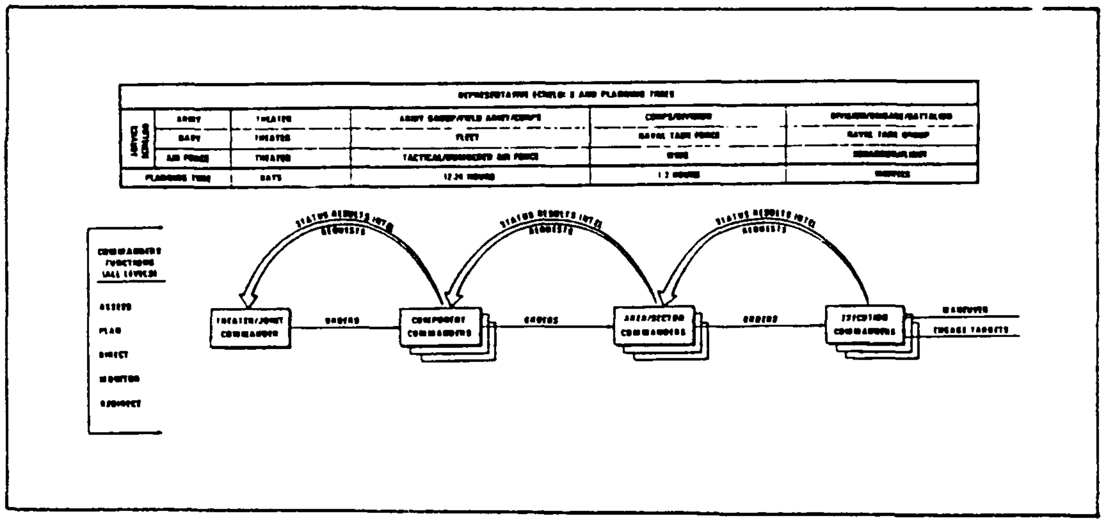


Figure 5.7.a Command and Control Process: Current

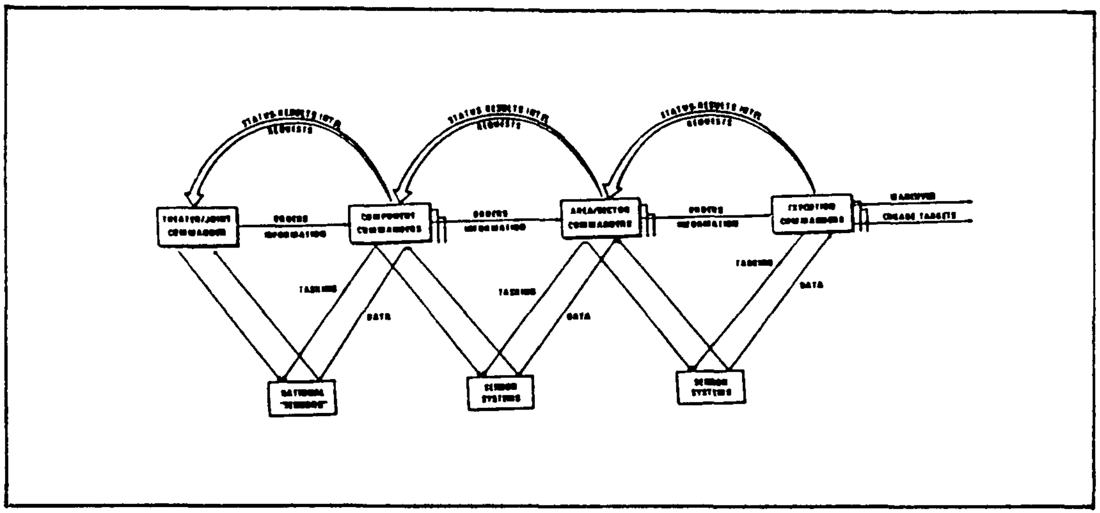


Figure 5.7.b Command and Control Process: Future

3. Command and Control Center Design

In Chapter III, the function of command and control was discussed as the transformation of situation evaluation into response implementation. Chapter IV states that the implication of this transformation function is done by information resource allocation and weapon resource allocation. During the battle, information about the environment which is an object of battle management is merged in command and control center, and decisions to control the environment to the desired state comes out from the command and control center. Figure 5.8 depicts the information flow around the command and control center.

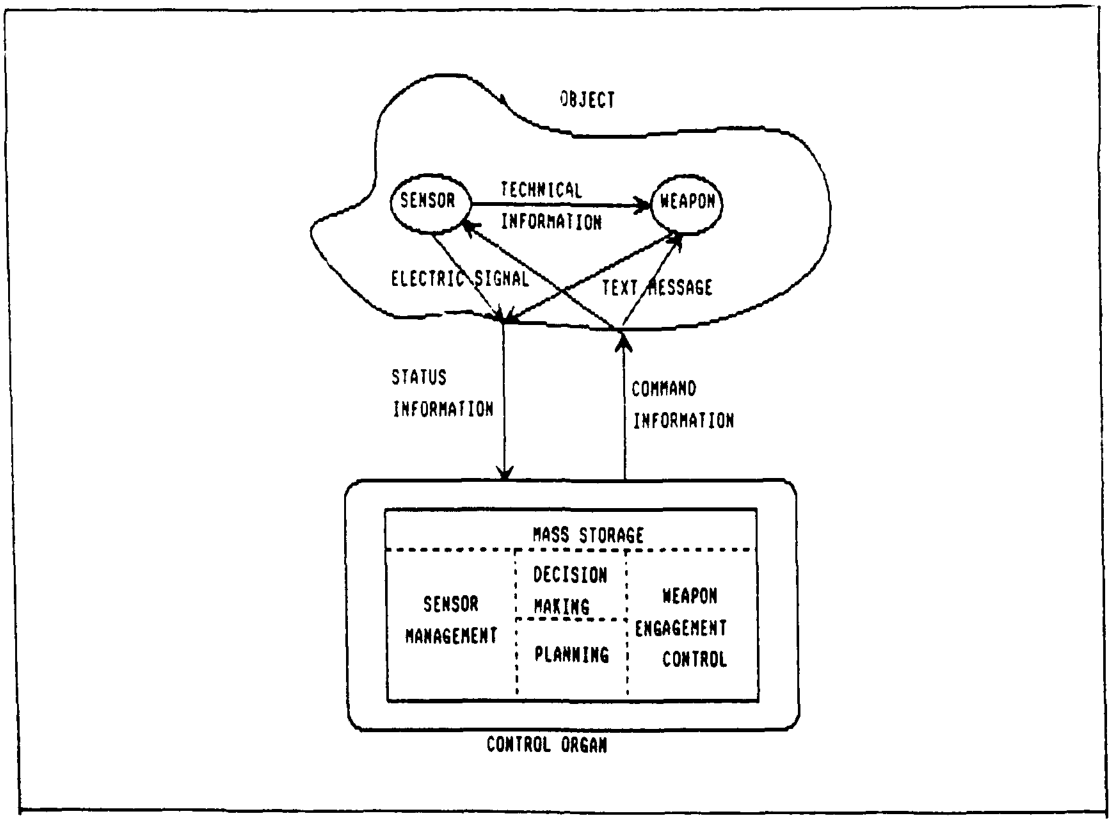


Figure 5.8 Information Flow around Command and Control Center

In cybernetics the decision making process is usually defined as conversion of status information to command information (or control information) by the control organ, i.e., conversion to information by means of which the tasks of the object of control are then assigned, and thus its actions and the functioning of the system as a whole are given a purposeful nature [Ref. 71:p. 14]. Once decisions are made, the control organ is dealing not with status information, but with material objects and action on them by transmission of command (control) information to them to implement the decision and plan [Ref. 71:p. 15]. Thus the structure of the command and control center will consist of four major functional modules connected with the unique information flow. That is, the information obtaining module, decision making module, task planning module, and operations control and monitoring module; input to the information obtaining module may be either electronic signal or text messages or both and the output of that module may be the status information to flow to the decision making module, and there will be task or action information between the decision making module and the planning module, finally command information flows into the operations control and monitoring module.

The architecture of the command and control center, then, is configured by the elements of the four functional modules and the information flow branches. Each functional module will be made up of various man–machines cells, and the information flow branches will be made up of the communications equipment and the protocols. The man–machine cells will be classified into the six "functional areas" as discussed in Chapter II; command, information management, engagement management, sensor management, communications management, and system management. On the other hand, the information flow branches will be classified

into three types of connectivities as discussed in Chapter II; command connectivity, coordination connectivity, and information exchange connectivity. Through the three types of connectivities, all information such as technical data transmission between machines, status information, and command information will flow with a form of electronic signal, text messages.

The part of man in man–machine cells of the command and control center is the commander, staffs, and technical system operators. On the other hand, the part of machine in man–machine cells will be divided into five major groups, based on the purpose and the nature of operations: communications equipment, information acquisition equipment, equipment for processing information and for performing tactical estimates, documentation and document reproduction equipment, and command vehicles (Figure 5.9) [Ref. 71:pp. 70–71]. In order to build the command and control center architecture these men and machines will be combined and assigned to the six functional modules. Then all functions are networked, and finally the standard operations procedures within the command and control center are set up.

When the command and control center architectures are designed, the first consideration is that the command and control center is one part of the large scale C^3 architecture. One methodology to design the command and control center architecture as a part of the large scale C^3 system is to set the requirements of a specific command and control center through the overall hierarchical chain of command and information flow line, then list all attributes which are related to the specific command and control center, found in the large scale C^3 architecture (the command hierarchy and information flow line). The attributes may be functions to be performed, the information systems to be used, the communications systems

connected, the messages originating there and the connectivity of the specific headquarters [Ref. 69:p. 72]. Then these attributes will be mapped to the functional modules of the command and control center architecture. Figure 5.10 [Ref. 69:p. 72] shows an example of mapping the attributes from the overall large scale C^3 architecture to the subsystem, command headquarters architecture.

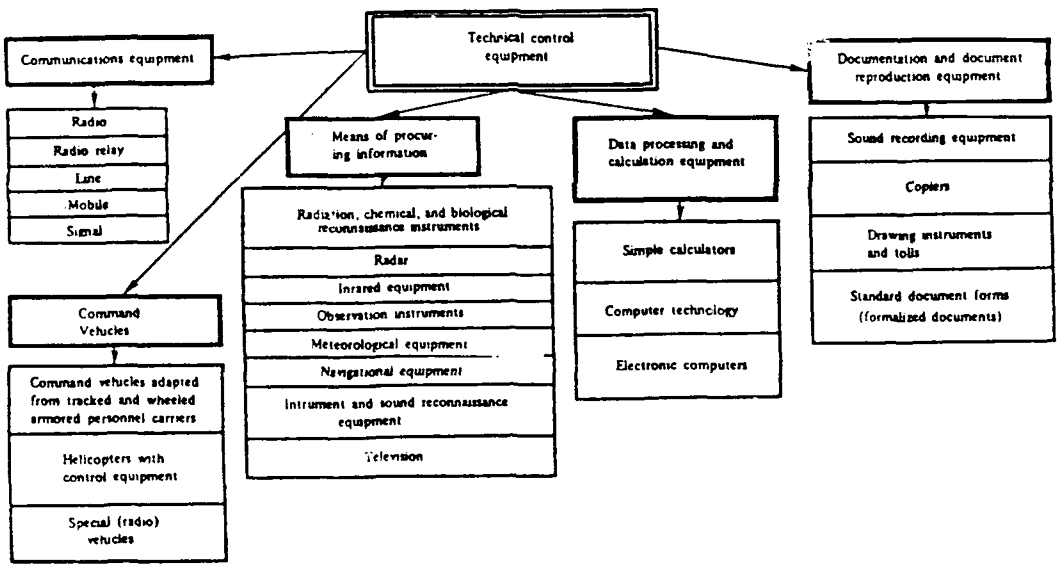


Figure 5.9 Technical Control Equipment

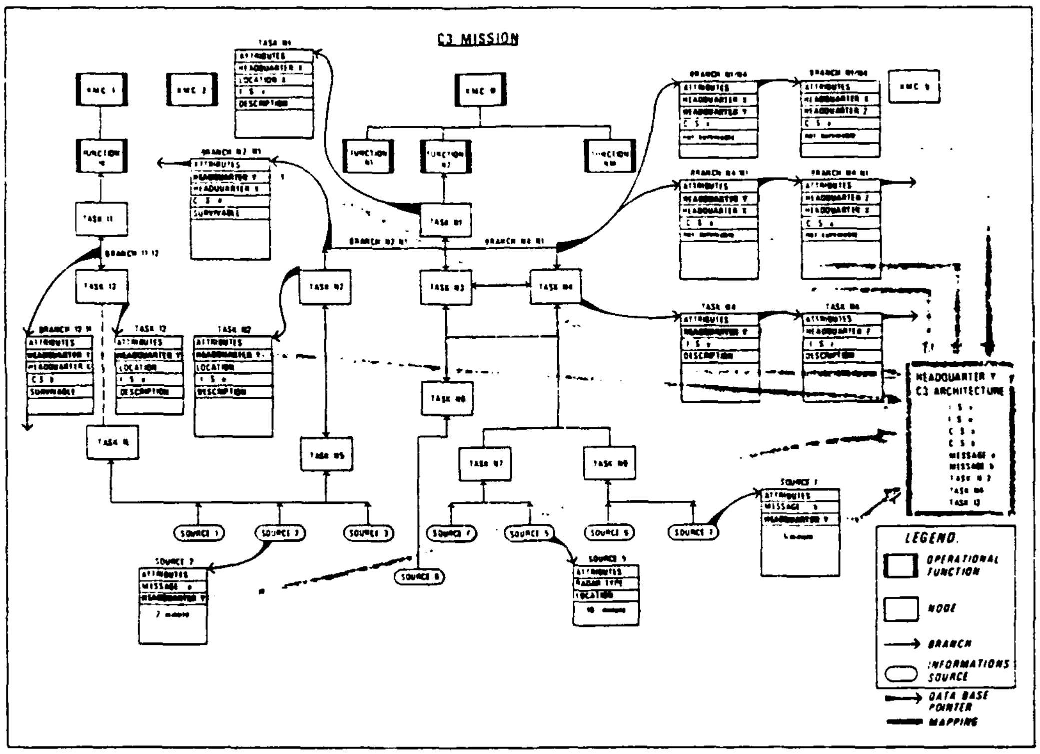


Figure 5.10 Design Method for a Command Headquarters in the Large Scale C^3 Architecture

4. Subsystem Design and Engineering

The subsystem architectures (hardware, software, people) of the overall C^3 architecture framework represent conceptual designs or systems specifications rather than C^3 planning. They can be categorized into two major types: physically oriented subsystem architectures and topically oriented subsystem architectures. Physically oriented architectures are defined by the physical constraints imposed on the architecture. Examples of physically oriented architectures are headquarters facilities, communications, information processing, and sensor architecture. Topical subsystem architectures describe an operational area (topic) such as air defense or intelligence. [Ref. 69:p. 72]

The methodology to develop the subsystem architecture has been presented in the above section. The methodolgy is to extract the attributes from the overall C^3 architecture and map these attributes to each subsystem. Then these items form a list of capabilities (baseline architecture) or requirements (goal architecture). [Ref. 69:p. 72]

The subsystem of people (commander and staffs) in the C^3 architecture has its own role and capability. In modern warfare, the capability of one–man command has limit on their capability because of the complexity of the battle situation and technical development. So Chapter II introduced the "hypothetical C^2 organization" to compensate the limited capability of one–man command. The subsystem of hardware and software in C^3 architecture are directly related to the specifications of the technical C^3 equipment. For the architectures of these areas, the OSI seven layer model and the C^3 Reference Model have been discussed already for software architecture. Also Chapter IV states that the C^3 system is based on the distributed, hierarchical network in the embedded organizational system which

determines the hardware architecture such as the location of information base, information processing technology, communications technology to meet the distributed network, and so on.

These architecture requirements are transformed into the technical specifications for system design and engineering under the constraints of system characteristics such as survivability, flexibility, security, user–orientation, interoperability, and reliability which are discussed in Chapter II. In terms of system acquisition, however, the design and engineering approach must be consistent through the whole system development so that the subsystems are compatible with those of the other systems and maintained and supplied properly in the battle. A typical approach is the Modular Building Block (MBB) concept to C^3I system approach. This approach has the potential for significantly facilitating the acquisition of DOD C^3I systems and for reducing life cycle costs of both fixed and mobile/transportable systems at the tactical level, crisis/contingency level, and strategic/theater level [Ref. 72:p. vii].

The basic concept is to build or assemble C^3I systems using physically and electronically compatible modules interconnected with a multi–purpose data bus which is capable of carrying voice, data, video signals, and control information and hence can be used to implement remote monitoring and control of the modules. The MBB is essentially a standardization and packaging approach which is independent of specific systems or mission equipments. The MBB concept does not attempt to standardize on specific types of manufactures of electronic equipments, communications equipment, automatic data processing, terminals, etc. The concept relates only to the packaging and interconnection of these items in a way which focuses on their interchangeability by virtue of standard physical and electrical interfaces to the data bus. [Ref. 72:p. 8]

C. C^3 SYSTEM MANAGEMENT

1. C^3 System Management Organization

The chain of command for operational employment of forces runs from the President to the Secretary of Defense and to the CINCs of the operational and combatant commands. By law, all forces must be assigned to one of the operational commands. Meanwhile, the Joint Staff, under the JCS Chairman, acts as the military staff to the Secretary of Defense for planning and operational direction of those forces. The Departments of Army, Navy and Air Force are responsible for the administration, training, and supply of their component forces assigned to the unified and specified commands. The functions of building force structures and supporting resources are accomplished in the chain of command from the Secretary of Defense to the Secretaries of the military departments. Approval by the Secretary of Defense for these is accomplished both on the basis of supporting plans developed by JCS and on advice from its Chairman. [Ref. 72:pp. 33–35]

In June 1982, JCS initiated action to improve the capability of the Joint Staff to focus on management of strategic C^3 and joint tactical C^3 systems. In subsequent actions continuing through 1984, JCS proposed and the Deputy Secretary of Defense approved the following major steps to improve C^3 management.

A C^3 Review Council chaired by the Assistant Secretary of Defense for Command, Control, Communications and intelligence (ASD[C^3I]) was established. And JCS reactivated J–6 (the command, control, communications systems directorate), which was eliminated during the post–Vietnam contraction. The C^3 management organization at the assistant secretary level and each military service level are shown in Appendix A.

The Defense Communications Agency (DCA) was realigned, with the DCA director reporting to the Secretary of Defense for acquisition related matters, and JCS providing guidance and direction for matters involving planning, requirements development, establishing priorities, operational concepts, policies and procedures. DCA has become the principal C^3 support activity for the Assistant Secretary of Defense (ASD) for C^3I, the Joint Chiefs of Staff (JCS) and the unified and specified commanders. The Director, DCA, reports to ASD[C^3I] and the Under Secretary of Defense (USD) (Acquisition), but receives his operational direction from the JCS through the J–6. In July 5, 1984, ASD[C^3I] directed the formation of Joint Tactical Command , Control, Communications Agency (JTC^{3}A) to solve the lack of interoperability of tactical C^3systems in each service during joint and combined operations. The structures of DCA and JTC^{3}A are shown in Appendix A.

DCA plans, engineers, manages and gives operational direction to DOD's long distance switching and transmission systems and the computer systems of the National Military Command System (NMCS). It also is the system engineer for the World Wide Military Command and Control System (WWMCCS). [Ref. 73:p. 91]

J–6 serves as the interface between the users (operational commanders) and the suppliers (military services). It develops plans, policies and concepts in support of the Commanders in Chief (CINCs), validates joint requirements, evaluates technically feasible and affordable solutions, determines joint implications and points of interface, tasks one of the departments to head a joint design and acquisition program, and accomplishes global C^3 system performance assessment [Ref. 73:p. 87].

JTC^{3}A's mission is to ensure interoperability in joint and combined operations through the development and procedural interface standards by the

military services. The approach is a four–step process: develop architectures for each theater or mission that will expose the points of critical interface and what data must flow across them; provide the technical and procedural interface standards for those points; test and certify that the standards work as intended; and monitor and enforce their use. [Ref. 73:p. 93]

2. Acquisition Strategy

One of the reasons that C^3 becomes a big issue in modern warfare is due to changes in computer and communications technology. In other words, high technologies inserted in modern weapon systems such as nuclear weapons, ballistic missiles, electronic warfare systems, etc. require more advanced technology in command and control in turn. Commercial technology in the information system field is, however, advancing at any extraordinary rate, and military people wish to benefit from this rapid growth like any user [Ref. 74:p. 106]. So industry and government must continue their joint efforts to maintain a balanced approach and provide C^3I solutions that are affordable, interoperable and integrated. A philosophy that industry and government can work together embraces total quality management (TQM). One must build quality into C^3 systems, instead of testing for quality. That is, all limited resources must be used wisely to craft quality into the design, manufacture and maintainability of future systems [Ref. 75:p. 23].

TQM is not a technique but a philosophy. Quality must be ensured by every function through the whole acquisition process, regardless of the jobs. Engineers are responsible for quality of design; secretaries for quality of typing; financial people for quality of a program budget [Ref. 77:p. 123]. Some steps must be taken for good C^3 quality management: the user involvement in system design, appropriate acquisition strategy, good government–industry relationships, etc.

User involvement in system design is essential especially for C^3 system design. The user (the command that is supposed to use the system) must be involved in the acquisition process because industrial designer does not understand fully the operational environment. The technical support by the industrial people and the operational support by the user will produce good quality.

Acquisition strategy must follow the best acquisition approach: Evolutionary Approach (EA) or Pre–Planed Product Improvement (P^3I). Each has its trade–offs. The evolutionary approach is usually adopted as C^3 acquisition strategy because: [Ref. 74:p. 114]

- it is so difficult to state requirements adequately at the beginning of a true C^2 program,
- such requirements are expected to change frequently over the life of the program,
- users cannot specify acceptability criteria adequately in advance due to the subjective nature of these criteria,
- an overall program to which the evolutionary approach is being taken may involve little or no advanced development of any type, such as when the user upgrades his C^2 capability through regularly adapting existing or modifiable commercial or military material. In contrast, P^3I approach ordinarily does involve advanced forms of development, and
- C^3 system acquisition has the strong real user influence over the acquisition. The fundamental need for continuous iterative interaction among all of the participants in the C^3 system acquisition process is basic to EA, whereas no such need exits in general under P^3I.

Evolutionary acquisition strategy is a system acquisition strategy in which only a basic or "core" capability is acquired initially, for quick fielding, based

on a short requirements statement that includes a representative description of the eventual overall capability needed and the architectural framework within which evolution will occur. Subsequent increments, or "blocks", of capability are then defined sequentially, based on continuous feedback from the lessons learned in operational usage; concurrent provider, user, and tester evaluation of the adequacy of the hardware/software configuration being proposed; and judgments of the improvements or increased capabilities that could result from application of new technology where feasible. [Ref. 74:p. 115]

Good government–industry relationships can save money and increase the quality. For example, the use of standard, off–the–self, non–developmental item as C^3 system components is the key to save money because the R&D cost has been paid already. Meanwhile, the contract, which establishes the relationships between government and industry is another factor to increase the quality of C^3 product. If industry tries to "hide–the–problem–until–later", the quality may decrease. So the source selection and the contract is essential to the government and industry relationship or coordination for the good quality.

3. Project Management

The considerations in project management exist in three categories: complexity of the program itself, the government incentive, and the industry incentive.

If the system is complex, then the government can not figure out what the system looks like until some visible aspects of the system produced. This uncertainty causes the acquisition plan to be updated repeatedly, and still causes questions of the operational use in the real field. The contractor is dependent on the system requirements or the subsystem specifications in the engineering phase. If

they can estimate the requirements further, they do not need to redesign the system whenever the requirements is updated. The best way to develop a system is for the user who makes the requirements to design and engineer the system, because the user will get the product as his own preference. But they don't have the capability. That is why industry takes over the engineering jobs. But, the user must have at least the capability to make the requirements consistent with the engineer's point of view and the industry must have at least the capability to see the system with user's point of view. But in that case, due to the uncertainty and complexity of the C^3 system, both sides are highly dependent on each other for the other's jobs. Usually, government is focused on just their requirements and industry is focused on their design and engineering. In order to solve the uncertainty problem about each other, it is necessary to provide more information about the program to each other. That is information exchange.

The main reason of the delay in the system acquisition schedule is the complexity of system. The Posistion Location and Reporting System (PLRS), which is a joint program of US Army and US Marine Corps, proved this. The program took 23 years from problem initiation to product delivery. The reason of delay in product delivery was due to the system complexity [Ref. 76]. But, if the government strategy to acquire a new system emphasizes quality rather than the delivery time, the delay will be compensated by the improved quality, because the significance rate of design parameters is ranked high on quality, low on delivery time. So government must set up the priority between the quality and the delivery time. That is a decision problem among the quality and delivery time required by the user, budget available to the program, and the capability to meet the required quality within the time.

What would be the strategy of the contractor? They will think about the benefit. The way to increase the benefit must be something different in C^3 programs. The total quality of any system is highly dependent on the system itself. TQM expert W. Edwards Deming maintains that 85% of quality problems are caused by the system; just 15% are caused by people [Ref. 77:p. 123]. So if industry people just focus on the quality of the system in R&D phase, 85% of quality will be guaranteed in the first stage of acquisition process. Thus source selection for a complex C^3 system acquisition is proposed to be a sole source selection because it save the R&D money and the type of contract is proposed to charge the R&D risk to the government rather than the contractor. Cost Plus Fixed Fee (CPFF) or Cost Plus Incentive Fee (CPIF) are examples of these types. The PLRS program is a good example of sole source selection and those kinds of contract types. Then there is no reason to try to make benefits in R&D phase. Contractors will focus just the quality of the complex system if they are not behind in the schedule for the loyalty of the company which is a sort of benefit.

D. TRAINING AND EDUCATION

Technological changes in the type of modern war have changed the types of military people's jobs, too. For more advanced command and control, C^3 systems must be developed and fielded with fully skilled people as well as highly technology–embedded equipment. The high quality of C^3I personnel is evident especially in jobs related to electronics repair and computers [Ref. 78:p. 103].

The speed of decision making needs to be accelerated and decision aids are needed to enable the staff to look at a wide range of options, each in more depth, and in near real time. What is the solution? The solution to acquire high quality C^3I people is through the short–term training and long–term education.

As the short–term solution, commanders need to practice in command to develop the technical and tactical competence and a leadership philosophy that will spark the needed behavior in the chain of command. Second, commanders must train on a realistic battlefield with the right tempo of battle and against a tough, competent enemy. Third they have to provide trained observers who can point out breakdowns or inadequacies in the commander/staff relationships and functioning and who can offer workable solutions. Fourth, they need a laboratory to provide focus for development efforts to enter into the era of tactical automation and expert decision aids– a laboratory to instruct what to teach staff officers. [Ref. 79:p. 28]

Generally the short–term solution has two types of programs: seminar type and simulation type. The U.S Army's Battle Command Training Program (BCTP) is a typical training model. The BCTP consists of two phases, a tactical seminar and a CPX. The BCTP seminar brings together commanders with their primary staffs and major subordinate commanders for a five day series of workshops and tactical decision exercise focused on AirLand Battle doctrine. The topics covered in the seminars fall into four major areas: doctrine/tactics, leadership, sustainment and threat. The second part of BCTP is the warfighter CPX. The warfighter exercise follows the seminar by two to six months, and BCTP conducts it in a tactical CPX mode. [Ref. 79:pp. 28–29]

The growth in computer hardware, software and applications over the past 10 years has opened up a door of opportunity for more realistic and varied simulations of both weapon systems and battlefield scenario [Ref. 80:p. 57].

Army simulations basically take the form of either computer assisted or fully automated simulations. Three different types of simulations are in operation: the seminar trainer, which is a stand–alone training simulation for very small audiences;

the command staff trainer, a single echelon trainer where one level of command can train by itself; and the larger simulation, the command post exercise driver, which serves as the multi–echelon trainer. The simulations in the Army can be conducted at different levels from echelon above corp (EAC) down to company level, and participating personnel are separated into two groups: training officers and role players. [Ref. 80:p. 57].

The Navy uses ships with high technology (SPH–1, 20B–4, and FFG–7) as simulators, which are controlled by onshore mobile units in many cases. To implement a pierside simulation, the training command for either the Atlantic or the Pacific Fleets would assign the ship an appropriate training unit for the ship's home port time. The ship's personnel would designate the desired areas of training, and the training commander would assign exercises, beginning with remedial efforts and working up to multiwarfare battle problems.

In the Air Force, one piece of simulation equipment, the System Trainer Exercise Module (STEM) serves in operation and testing of new command, control and communications gear entering inventory, and it functions as a trainer and exerciser in conjunction with the tactical air control system. [Ref. 80:pp. 59–60]

As the long–term solution, the education reform is a long–term project requiring a national level commitment. With a growing emphasis on computerized communication and intelligence functions, such systems tend to be more complicated than their predecessors and will increase the requirements for skilled military technicians. In 1945, approximately 10% of the enlisted personnel were assigned to technical jobs. Today, that number is 30%. Moreover, approximately 45% of current recruits perform work that would be classified as white collar in civilian life. [Ref. 78:p. 101]

Estimation, quantitative and problem solving skills are lacking in entry level employees at the post–high school level, and because these skills are gatekeepers for technical careers, there is a shortage of people making technical career choices in colleges or the military [Ref. 78:p. 102]. Thus a long term education program must be developed in college or military organizations in order to acquire the high quality of C^3 people. The program will focus both on the technical background about the computer, communications, and information system and on the problem solving skills such as mathematics, operations research technique; and decision theory.

VI. C^3 DEVELOPMENT CONSTRAINTS AND ENVIRONMENT

A. C^3I SYSTEM DEVELOPMENT CONSTRAINT

1 User–Developer Relationships

The successful acquisition of a C^3 system requires participation by both users and developers. The extent of involvement of users and developers varies with the type of system being acquired (Figure 6.1) [Ref. 81:p. 320].

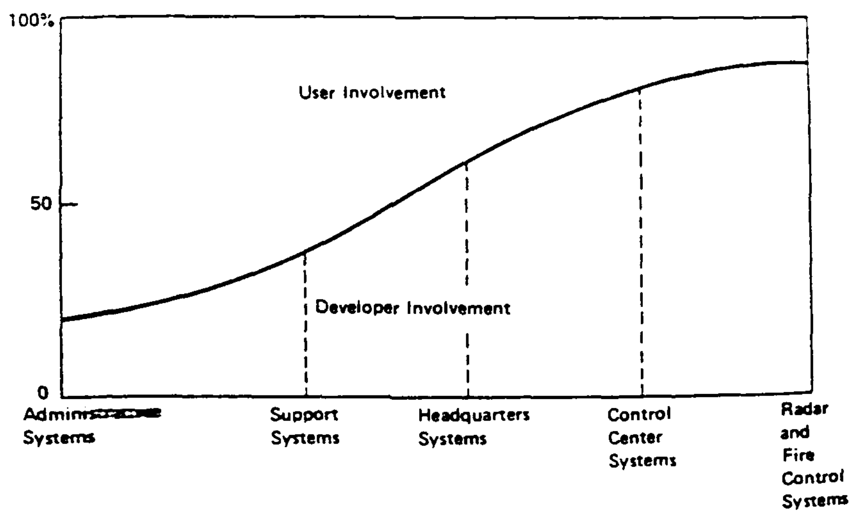


Figure 6.1 User–Developer Involvement

As it moves from the more physically constrained, high technology radar or weapon systems to the inventory or payroll systems which support the administrative needs of the command, the chance of funding off–the–shelf processing capabilities increases. For sensor systems, most of the processing is in line

with the desired capability and serves to tailor the components to the physical and electromagnetic environment. The disciplines and experience required are more likely to reside with the developer. The greatest difficulties in C^3 system acquisition have been associated with systems to support the higher level commands. For headquarters type command systems, the processing is generally in the form of management and decision aids and must be tailored to the command tactics, procedures and operational style. In these systems, the experience and discipline required lie more heavily with the user. [Ref. 81:pp. 320–321]

Progress has been made in recognizing the need for user participation in system development, especially in the software aspects of command and management systems. Operational employment plans must be kept up–to–date. Early attention to creation of the operational database, to system training and evaluation and to the need for overhead facilities is required. Continued consideration of these factors as the program develops is also necessary. [Ref. 81:p. 321]

But the participation must take place in a responsible way or requirements will escalate or change frequently. A more formal process of requirements definition, evolution and control is needed to make the user more accountable for requirements, to coordinate across user staffs and to reset requirements as experience (more realistic cost and performance tradeoffs) becomes available as development proceeds [Ref. 81:pp. 321–322].

The combination of the user's role and the developer's role in system development is a critical element to the success of the system acquisition and the performance of products. When users are familiar with the industrial technology required to develop an information system, the technology is considered as a

relatively low technology. And the frequency that the user is involved in project management will represent the structure of project management. Let the organizational experience with the industrial technology (or the user's background knowledge about the developer's technology) be rated as high technology when the user knows little about the technology to be used in system development; low technology when the user knows much about it, and the project is managed in the low structured method when the user is involved in the project frequently; in the high structured method when the user is involved in the project seldomly. Then the risk of the success for the system development will be represented by four classes. Table 6.1 shows the relationship between the acquisition success and the degree of user involvement [Ref. 82:pp. 430–433].

Conventional development approaches used to define system requirements involve developer and user inputs early in the definition process and late in development. Early in the definition phase, the developer and user state mission and operational objectives and guide the development of requirements specifications. They then approve these specifications and give the contractor approval to build the system. As the development process proceeds to system–level testing, the developer and user again enter to evaluate results. At this point requirements deficiencies may surface, and it becomes necessary to modify the approved system requirements specifications and corresponding design. In some cases, the existing design is not flexible enough to accommodate all of the desired changes. One solution to avoid these serious shortcomings is the Martin Marietta system development approach presented by Martin Marietta Aerospace. Figure 6.2.a and b show those conventional and Martin Marietta system development methods. [Ref. 83:p. 158–159]

Table 6.1 The Risk of System Development Success

		PROJECT STRUCTURE	
		HIGH	LOW
RELATIVE TECHNOLOGY	HIGH	MEDIUM RISK	HIGH RISKY IMPLEMENTATION
	LOW	SMOOTH IMPLEMENTATION	LOW RISK (SUSCEPTIBLE TO MISMANAGEMENT)

The key element of this approach is early simulation in the C^3 Systems Laboratory using the C^3 Simulation Software (C^3SS) which was developed in–house as a real–time system to provide graphic display capabilities through an event–driven simulator. And the C^3I Systems Laboratory was designed to simulate the operational environment and provide a realistic operational center to demonstrate operational concepts and procedures. The simulation is based on the system operational concept and appropriate scenario. At this simulation point, the system requirements and user direction is revised in addition to the conventional approaches. The development phase then proceeds with minimum risk and avoids the problems of conventional methods. This method is able to minimize development risk by avoiding, eliminating, or reducing the possibilities for inadequate operational concepts, an efficient or complex design, workload imbalance, and complex or confusing user interaction. [Ref. 83:p. 159]

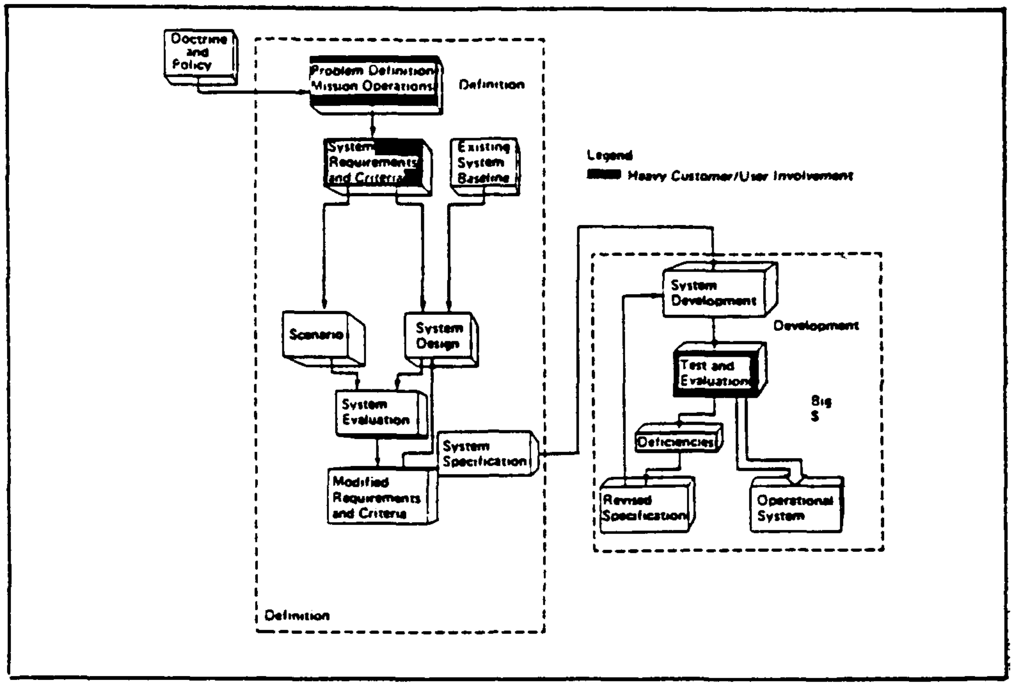


Figure 6.2.a Conventional System Development

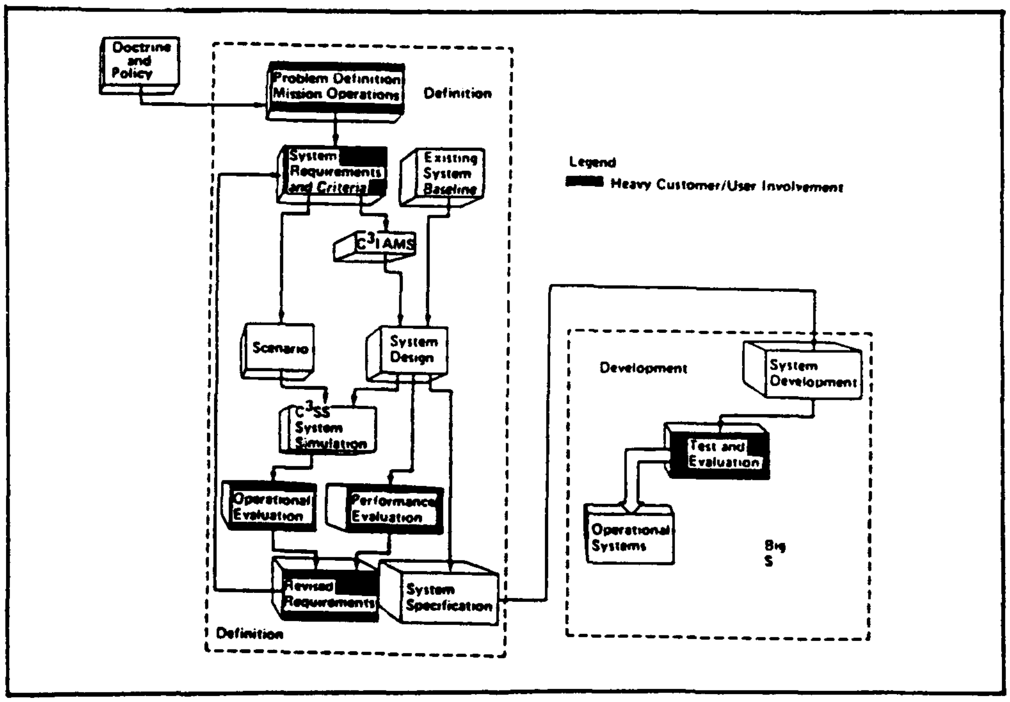


Figure 6.2.b Martin Marietta System Development

2. State of the Art

Problems within the C^3I environment are calling for new technical approaches to satisfy the unique situations facing commanders. In order to solve complex and difficult C^3 problems, the systems needed are those that perform complex problem solving operations; that can process a multiplicity of signals; that possess common sense knowledge and reasoning ability; and that can recognize anomalous behaviors [Ref. 84:p. 34]. The DOD has a large program sponsored by Defense Advanced Research Projects Agency (DARPA) to address potential solutions. The DARPA program has a goal of improving the cost and space requirements for the hardware and software. Specifically, research programs address performance advances in the areas of expert systems, natural language processing and distributed problem solving [Ref. 84:p. 36]. Expert systems are probably the best known subdiscipline of AI. There are, however, limitations on the current capabilities of expert systems to solve a large, complex C^3 problem. The limitations are:

- The power of AI is most formidable when it is focused at a specific, amenable target. Expert systems technology is best applied to well–bounded, simple problems. But there are countless bounded problems in C^3 [Ref. 85:p. 178]. It is difficult to apply the AI technology to a large complex problem.
- The representation of knowledge remains a challenge. The emphasis in knowledge representation has been on the experiential knowledge of an expert. Most representations have been less than adequate for representing causality, functionality and structure [Ref. 84:p. 38].
- Expert systems have limitations in extending their knowledge. Humans extend expertise in a variety of ways: by learning; by reasoning through use of

analogy to similar problems or events successfully dealt with before; or through going to an outside expert to handle a problem that is beyond their own expertise. It is, however, difficult for current AI systems to determine what is outside their own boundary when an event occurs out of its own domain. And attempts have been made to have streams learn by examples, by being told and from the system's memory of its own performance, but, in general, most AI systems show no evidence of learning. [Ref. 84:p. 39, quoted from Barr and Feigenbaum]

. Part of the difficulty in dealing with unanticipated events also stems from the heavy reliance on empirical associations, which are considered to represent only the surface knowledge of an expert. When an unanticipated event occurs, the expert may extract from the deep structure of his expertise a new rule to cover the unusual occurrence. It is precisely this deep stricture that is not available in most expert systems today [Ref. 84:p. 38].

. In addition, building knowledge bases for expert systems causes a bottleneck, either because it is so time consuming and thereby difficult to obtain from humans or because human experience and experts do not exist for some domains (e.g., nuclear weapons release authority) [Ref. 86:p. 166].

AI represents one class of methods among many in C^3 problem solving. State–of–the–Art involved in C^3 problem solving includes many analytical methods such as operations research, decision analysis and conventional computer science (non–AI) as well as AI. They all have their strengths and weaknesses [Ref. 85:p. 177]. These technologies can serve the optimal information resource or weapon resource allocation and fast computing speed for command, control and communications. Limitations of these analytical methods to apply to real C^3 system development are that the optimal resource allocation (state information, command

information and weapon allocation) and faster timing itself are not enough for C^3 problem. C^3 deals with human factors. Transformation of state information into command and control information is followed by the control function of C^3. This control function is conducted by controlling the objects, that is, material such as information or weapon. In fact, this is actually done by controlling human objects who are the operators of the physical material. But the current analytical methods are developed in material environment and mathematical science, not in human factors. But the human factors in C^3 problems are especially significant. For example, C^3 in special operations command requires more human motivation rather than control to accomplish their mission. If some decision support system assigns tasks to the forces based on the availability of assets and its utility (material oriented decision) regardless of the force's motivation, it will increase the probability of failure in a high motivation requirement mission.

Another aspect of the current state-of-the-art is limited to the lack of skills in software development. It is very difficult to develop an information system that works perfectly to meet the desired functions of the user even if the application models are developed in the best analytical way. Current software design and engineering skills usually result in errors in the implemented products. Once the software is developed, the product requires continuous maintenance through the system life cycle to account for the incorrect functions or the system extension. In software development, specific software errors are frequently classified into one of three categories: requirements errors, design errors or coding errors [Ref. 87:p. 241]. According to the result of the AIAA 1977 Software Conference [Ref. 87:p. 245], the number of design defects exceeds the number of coding defects. Thus software design skills must be emphasized to develop better information systems in addition to the improvements of AI technology and the analytical sciences.

3. Budget Constraint

According to a report presented at the AFCEA 7th Western Conference and Exhibition [Ref. 88], the defense budget for C^3I mission area has increased gradually. Even though the budget for C^3I area increases gradually, it still has a constraint that a fixed defense dollars is allocated to the C^3I area. For example, in FY–86 the total money for US national wide C^3I was 14,642.7 million dollars, and 17,253.8 million dollars in FY–88 [Ref. 89:p. 199]. On the other hand, the required money for C^3 system acquisition and operation is accumulated year by year because the operation and support money is added to the R&D money due to the software maintenance costs. Under these constraints, the C^3I systems must be developed to meet the requirements.

In this environment, a good economic analysis is required to solve the budget constraint. Estimating costs for the entire C^3 system procurement is not enough for C^3 project management. Cost analysis relative to system functional capability and alternative system development actions is more realistic within the constant level of dollars. Specifically, the cost analysis must be conducted through the whole system life cycle cost, because the C^3 system development includes information system mostly with a small portion of hardware, and the information system maintenance requires continuous commitment of budget through the system life for the software maintenance. Usually the system life cycle cost for communications/electronics system is distributed in three phases as shown in the Figure 6.3 [Ref. 90:p. 164]. But in information system development, the portion of operations and support costs is bigger than the usual case. According to Dr. Barry Boehm, speaking at the Software Summit Series in Los Angeles in May 1980, the cost trends for both software development and software maintenance are rising substantially and are not projected to improve (Figure 6.4) [87:p. 241].

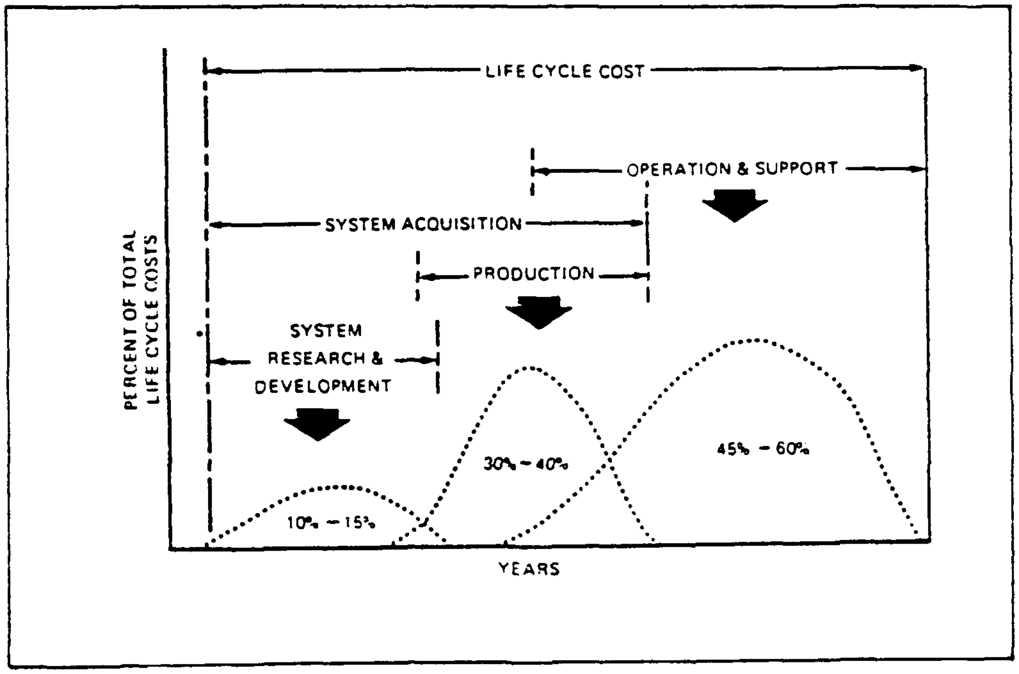


Figure 6.3 System Life Cycle Cost

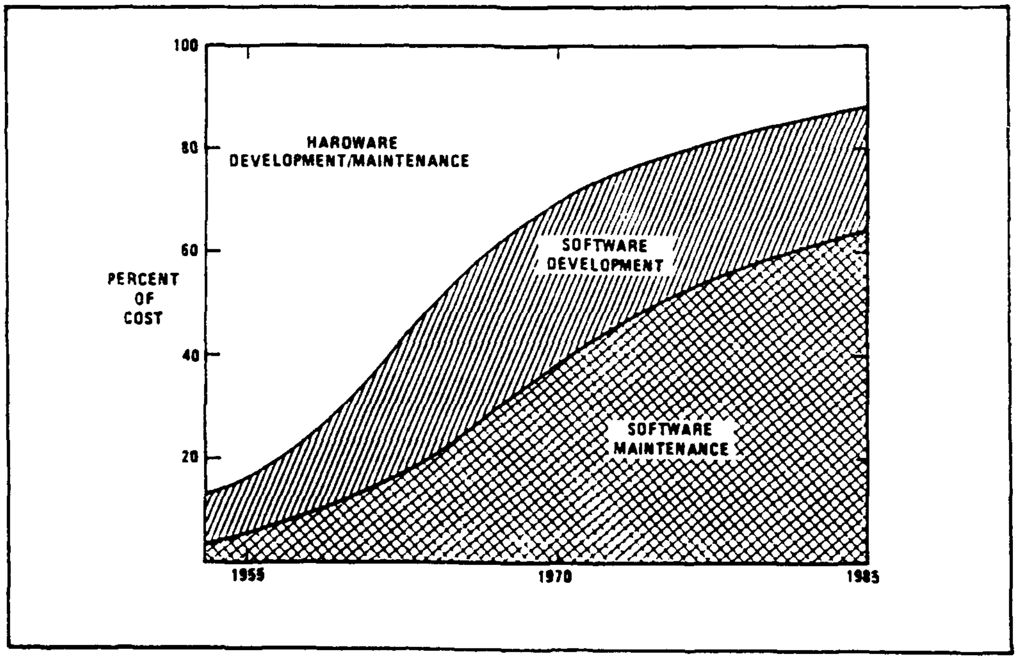


Figure 6.4 Hardware–Software Cost Trends

Thus, for the successful acquisition of C^3 system, the system life cycle cost must be carefully estimated so that the project would not stopped due to the lack of budget during the middle phase of acquisition, which is supposed to be used for maintenance and operations support. Multiple applications of the economic analysis such as design–to–cost (DTC), design–to price, cost–benefit analysis, cost–effectiveness analysis, POM (Program objectives Memoranda)/FYDP (Five Year Defense Plan)/budget formulation, cost credentiating, and discount rate, etc. will be considered as directly applicable methods to usual system cost estimation. For the C^3 system acquisition, however, they will be reviewed again based on the the unique C^3 system development environment, that is, the information system development environment.

B. C^3I SYSTEM SUPPORT ENVIRONMENT

1. Operational Readiness in an Organization

A full scale development of C^3 system in an organization includes both organizational system development and functional transformation system development as shown in Figure 3.2 (page 61). But it is very difficult to develop both at the same time. Even the functional transformation system which major system will be the information transformation systems can not be developed simultaneously because of the budget or labor, etc. When a part of those systems is procured, then, the operational readiness of the organization or force must be prepared in order to operate the system effectively and economically. For example, assume that a company has produced a car, but the car can not be in operation due to the lack of gas and poor road conditions, not because of the defects of the car itself, then the company loses money until it is in operation.

To prevent this undesired situation, the operational readiness must be analyzed and measured. And the priority of each project, which is directly related to the C^3 system or affects the operation of the C^3 system indirectly, must be assigned when the C^3 system is planned and initiated. Then how can the operational readiness of an organization be measured? The answer to this question may be the solution of this problem.

One alternative method is to measure the connectivity of the new C^3 system to the existing C^3 network not just in terms of hardware such as links and nodes but also in terms of network entity. A similar concept is proposed by Lee and his team in "operational readiness performance measures of a C^3I network" [Ref. 91]. According to Lee, the probability of a C^3I network being available when it needs to be accessed is called operational readiness. In other words, operational readiness is defined as the probability that the component is ready for use at a given time [Ref. 91:p. 32]. The basic concept is explained by the following statement [Ref. 91:p. 31].

> Since no components can contribute to system performance unless they are operationally ready, the operational readiness is the fundamental measure. The purpose of a C^3I system is to support the information exchange requirements between various users within a command and control organization. There is a set of performance indices associated with each entity when it is in an operational state. The performance index is a function of the internal behavior of the entity. However, because of its internal behavior, an entity may not be available for use at a given moment. Therefore, when evaluating the performance of a C^3I network, one has to incorporate the probabilistic nature of operational readiness and the probability that an entity is ready for use whenever it is needed into the overall performance measure.

According to the boundary of the entity, this operational readiness can be defined as just the hardware connectivity consisting of the links and nodes, or as

the force organizational connectivity consisting of each specific sensors and weapons related to the C^3 system. In the large scale C^3 network, the entity can be extended up to the adjacent C^3 network entities. Analyzing the wide range of the entity, one can plan for effective, economical use of the new C^3 system. For example, from the small boundary of the entity parameter analysis, one can adjust the requirements about the transmission rate, media, capacity, etc. which is used for the C^3 system operation within the force organization and plan to acquire them; from the broad boundary of the entity parameter analysis, the project management agency can modify the existing C^3 system acquisition plan and assign the priority to each system acquisition project again according to the updated plan. For an automatic early warning system, which networks between the Air Defense Artillery in the ground and the Air Strike Planning Team in the air, the exchange of a few liaison officers with voice communications equipments such as telephones and FM radio is not enough to meet the effective operation of the early warning system. It may require a fiber optic transmission media with machine to machine connection without the intermediate phase such as the liaison officer's assistance. For this requirement to be met, the force organization must acquire new communications equipments and modify the operations procedures.

Thus, to find the entity to connect both the existing C^3 network and the new developed C^3 system and to define the boundary of the entity is essential to measuring the operational readiness and preparing the force organization in order to operate the new C^3 system.

2. Human Capabilities in Man–Machine Interface

The purpose of the C^3 system is to support the commanders in decision making. The way to support the commander is through the interaction between the computer and the commander (man–machine interface). The portion of computer's support to the commander, then, can be presented by the success of the input/output to/from the computer in the desired matter. Even though the qualitative or quantitative capacity of an information system is the same, the quality of the C^3 system operation output can vary according to the success of the operator's (commander, staff, or technician) capabilities to use the system at the maximum full rate. For example, a decision support system such as a spreadsheet type personal computer package can be used as a powerful statistical analysis method for an expert who is familiar with the package itself, and the essentials of the problem must be solved with the spreadsheet. But for the poor analyst or the person who has the poor knowledge about the function or power of the applications models embedded in the spreadsheet, it is just a bunch of mass storage and a simple calculator and not a decision support system.

The owner's capability relative to the C^3 system (especially the C^3 information system software or hardware) will be classified with two major types. One is the basic knowledge about the computer itself and the essentials of the problem facing him. It is not a perfectly intelligent system. The basics of the computer is obviously that it is a machine and calculator. So there can be a kind of error in its output from the logic of the developer to the technical malfunction of the subcomponents. The decision maker must not trust the output of the information system at 100%. His decision must not always rely on the output of the computer. Remembering this, the owner must have his own operations strategy when he is

facing a problem. Then the decision support system will be operated based on the strategy. In other words, there is no standard way to solve a problem. The owner must study and try to find the answers to

. what kind of problem can he solve using the C^3 information system?

. how can he solve each problems?

. what is the limitation of this system?

. how can he cover these limitations?

These answers will provide the owner with the way to use the system in an effective way without a critical undesired conflict.

Another type of capability is the owner's input skill and the output interpretation skill. If a battle manger has some information which must be disseminated to a certain destination or broadcast over the whole forces, he must be able to identify the best information path route including source and sinks and input into the selected source computer with a proper form using any input devices such as a keyboard for text message, a voice recognition device, a scanner for picture or graphical type information, or sometimes facsimile.

The output interpretation skill is also significant in decision making. During World War II, the Pearl Harbor case is a good example of poor interpretation skills. Most C^3 system (decision support system) will just provide a type of information, except for a few specific expert systems. Then the capability to interpret the output (information) from the information system (any type of information system) determines the value of output or information.

If there is a lot of time delay and errors in input or output in interaction with the C^3 information system, the value of information from the system is reduced as much as the degree of time delay and errors. If the time and error are

sensitive to the decision making, the value can be zero in some cases. These time delays and errors in both input and output may be caused by lack of experience, poor knowledge about the problem or computer itself, or owner's physical or physiological conditions. Thus the owner (commander, staff, technician) will be trained and educated with background knowledge about the computer and its applications models to problems facing the owners using the information system.

VII. RECOMMENDATIONS

A. CURRENT TRENDS OF C^3I SYSTEM RESEARCH

The command and control problem is central to national security. In the top command level such as theater, joint, or combined operations command level, the direction of development of the military application models is primarily toward command, control, and communications [Ref. 81:p. 151]. Over the years, the demands made on command and control systems have grown exponentially. The increased range, speed, and accuracy of weapons systems have significantly increased the commander's volume of interest and, at the same time, decreased the reaction time. Concurrently, technological developments have provided commanders and their staffs with more capabilities to cope with the C^2 problem [Ref. 44:p. 25]. But most of the technology involved in this process is new and has never been in large-scale combat [Ref. 81:p. 152]. Each technology involved in the C^2 theory has been already established in its own field such as control theory, communications theory, information theory, acquisition theory, system evaluation theory, organization theory, combat modeling, etc., and they are still progressing in their own fields. In fact, C^3 is the integration of all these areas. Figure 7.1 shows the potential relevance of C^3 theory [Ref. 44:p. 25].

The second trend of C^3 research in western countries is that the research is oriented by "The American Way of War", which is defined as: [Ref. 67:p. 179]

- machine oriented rather than human oriented,
- technology driven rather than doctrine driven,
- attrition dominated rather than maneuver dominated, or
- industrial approach rather than agile approach to war.

These are less visible, but nonetheless very influential, causes of the poor performance of C^3 products. This trend says that if military forces have a command and control problem, look first at a technological solution to this problem. Sometimes this works. But when this tendency goes too far, the people who do the designing of command and control systems lose sight of the human dimension.

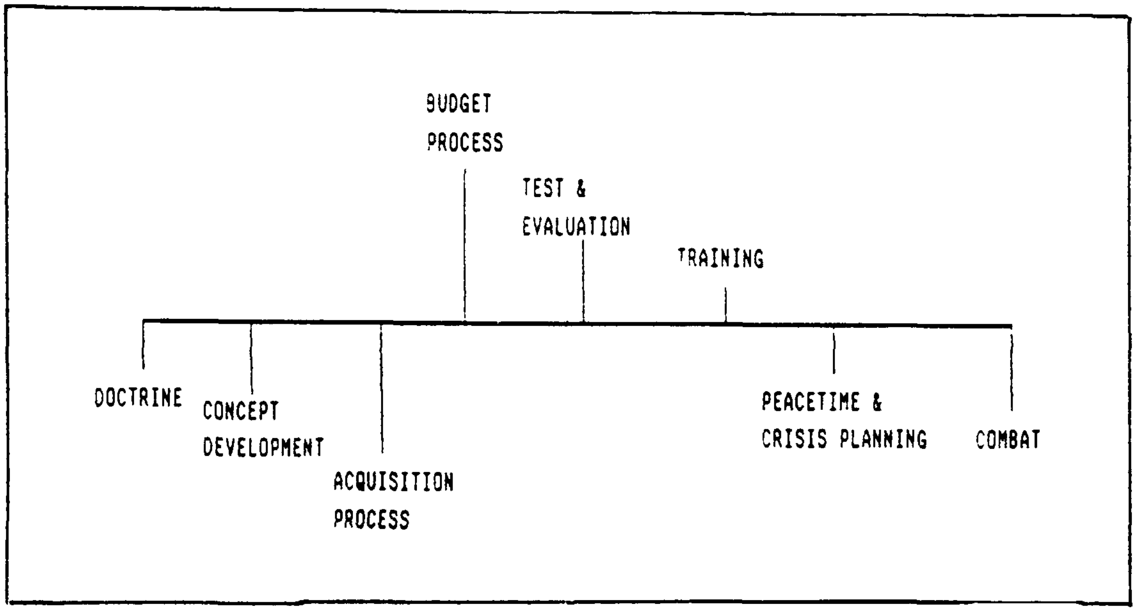


Figure 7.1 The Potential Relevance of C^3 Theory

During the last 10 years, the US defense RDT&E budget has been increased gradually. The budget which has been allocated to each mission area, however, shows that the C^3I mission area has been emphasized year after year. Figure 7.2 shows the trends [Ref. 88].

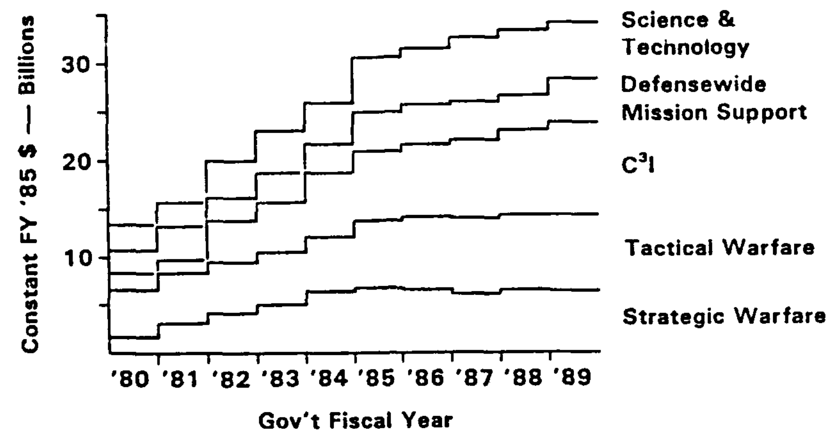


Figure 7.2 Defense RDT&E Budget: Mission Area Trends

As shown in the figure, the R&D money primarily was allocated to tactical/strategic weapon systems prior to the middle of 1980s, but after that the money was scheduled for research and development in the science and technology area and the C^3I area. It is natural. The world has enough weapons to destroy the Earth. Now the integration of the effectiveness of those weapon systems is a key point of defense strategy. Also the world may not be able to increase its budget for new weapon systems due to the disarmament issue. Then the only possible way to increase the force power is to have the existing forces generate their full rate power performance. That is possible through the effective command and control of the forces. Good C^3 systems multiply the forces; poor C^3 systems divide the force power.

B. RECOMMENDATIONS FOR FUTURE C^3 RESEARCH

While everyone believes that C^3 is important, it is less widely accepted that a theory of C^3 is important. The process of developing C^3 systems begins with concepts and doctrines. More realistic results will be obtained if the C^2 implications of a proposed doctrine, war fighting concept, or weapon systems are considered from the beginning.

The development of C^3 systems is unique compared to the other weapon system development. In a usual weapon system development it is possible that the whole development process may be decomposed into sub engineering phases, and design engineers can work out their tasks alone even though they are not familiar with the complexity of the battle situation. The role of the C^3 system, however, must be emphasized in terms of a force integrator. So without the fundamental understanding of the battle and the various weapon system's characteristics, it is nearly impossible to develop a good force integrator.

For this, C^3 system development researchers must have their professional community and professional journal in applications development. At the same time, C^3 research must be at the academic threshold including all related academic areas such as decision making, computer and communications technology, operations research technology, psychological theory, organization theory, cartography, economics, national security, etc. This academic involvement is essential to developing a C^2 theory.

Second, the western way of solution to the command and control problem must be more focused on human factors such as leadership and motivation. The command and control system for a platoon leader is simple. It is a direct communications equipment such as a telephone line or FM radio. But a more

significant aspect of command and control is motivation, which represents the unity of effort of individual rifles. The unity of effort is the essential requirement of the C^3 system. Of course, in the top strategic level, the C^3 system requires more complex hardware and control rather than the motivation of the subordinate commanders. Studies about C^3 must include the human physiology related to motivation, and this be considered as a designing factor.

Thirdly, the C^3I system is no longer considered as just an adjunct to a weapon system but instead is now looked on as providing the capability to combine individual weapon systems into an integrated, effective force. And more budget must be committed to the C^3 R&D, or the budget must be at least equal to the other major weapon system development.

C. FINAL COMMENTS

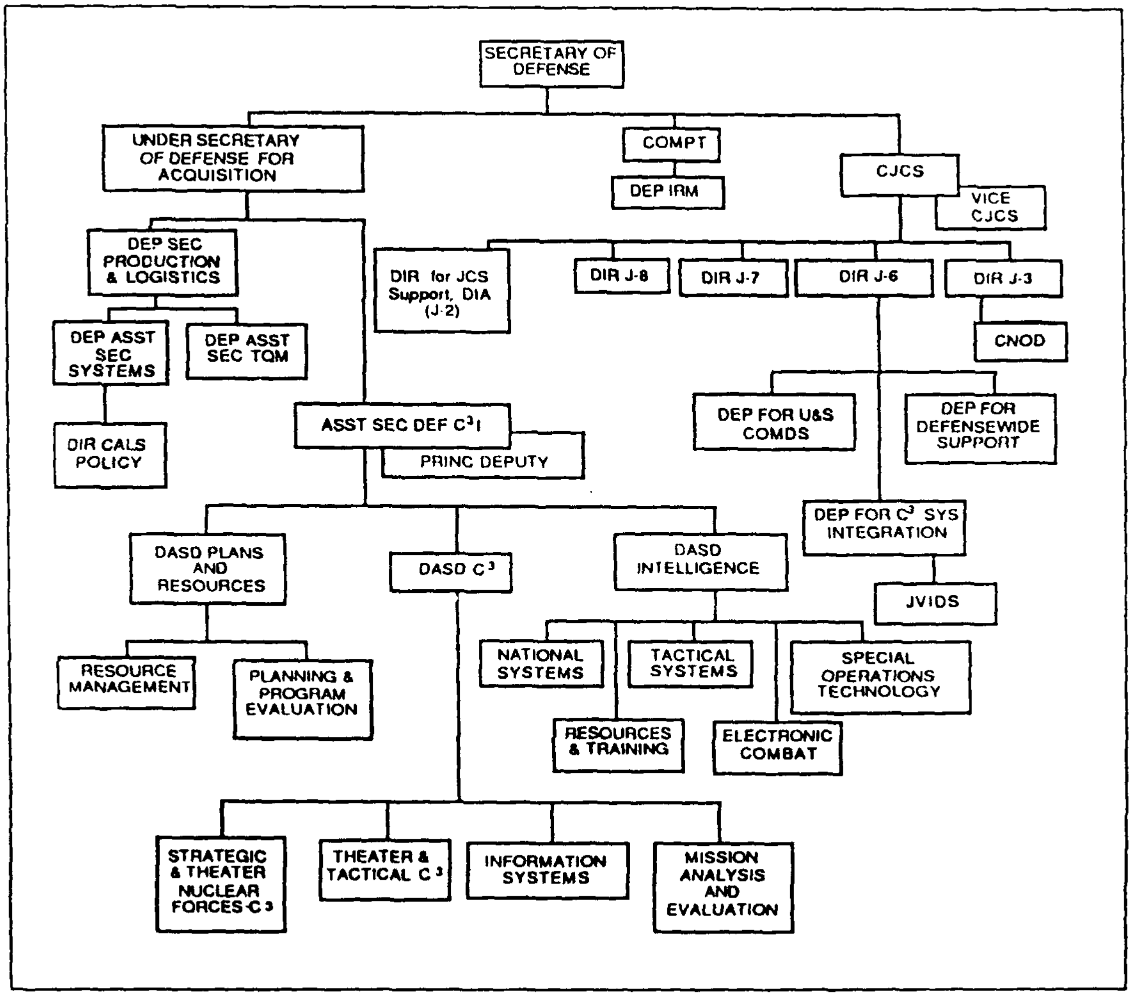
The purpose of this thesis is to provide a background knowledge about the C^3 concept, system, design, test, trends, and so on. So most parts of the thesis are broadly descriptive and comprehensive. For application of the thesis to the C^3 system development, the contents must be expanded and modified in a realistic matter. The author will leave this to the project manager's fatigue and system design and engineer's efforts.

APPENDIX A

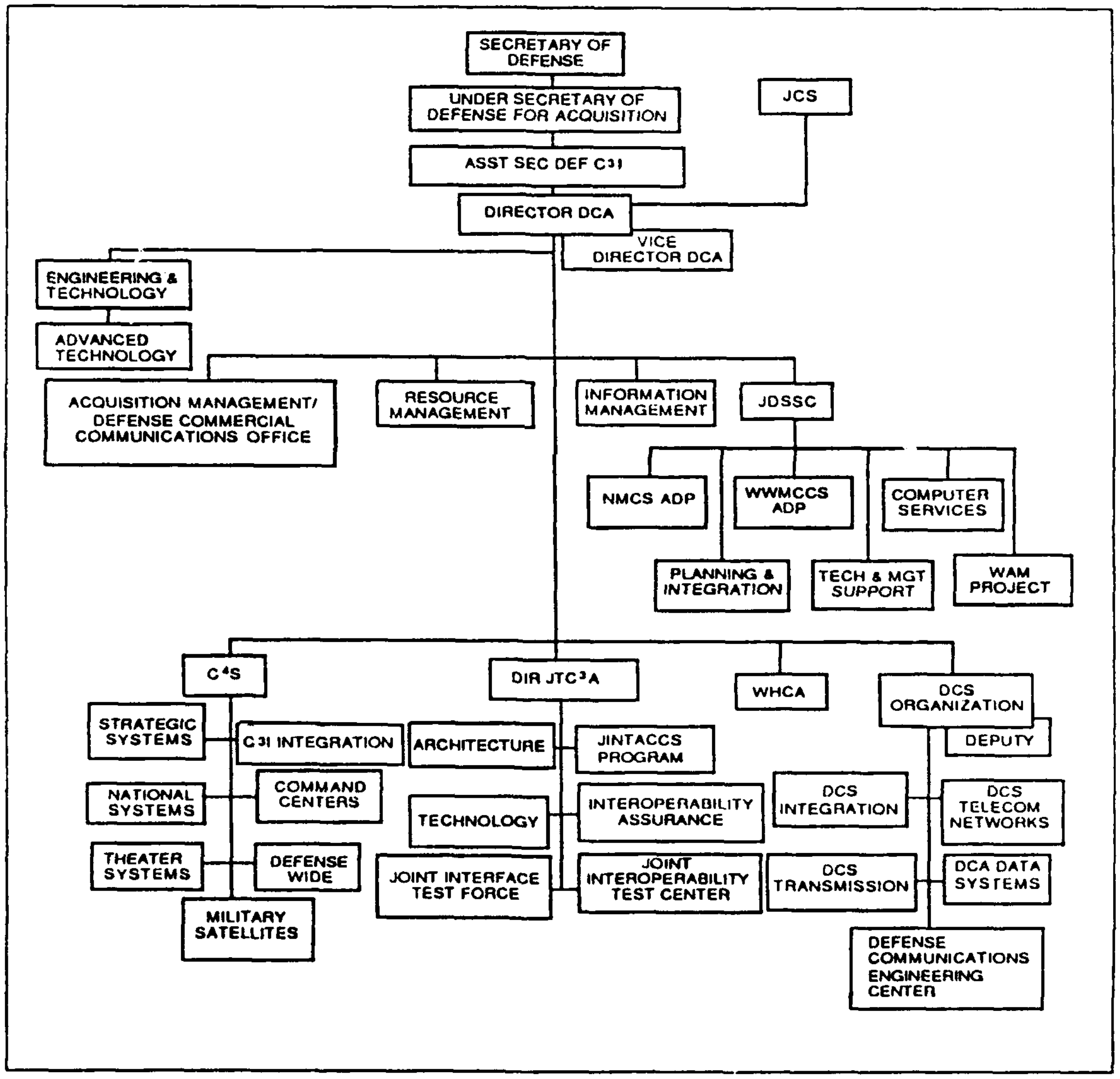
U.S C^3 MANAGEMENT ORGANIZATIONS

[Ref. 92:pp. 86–91]

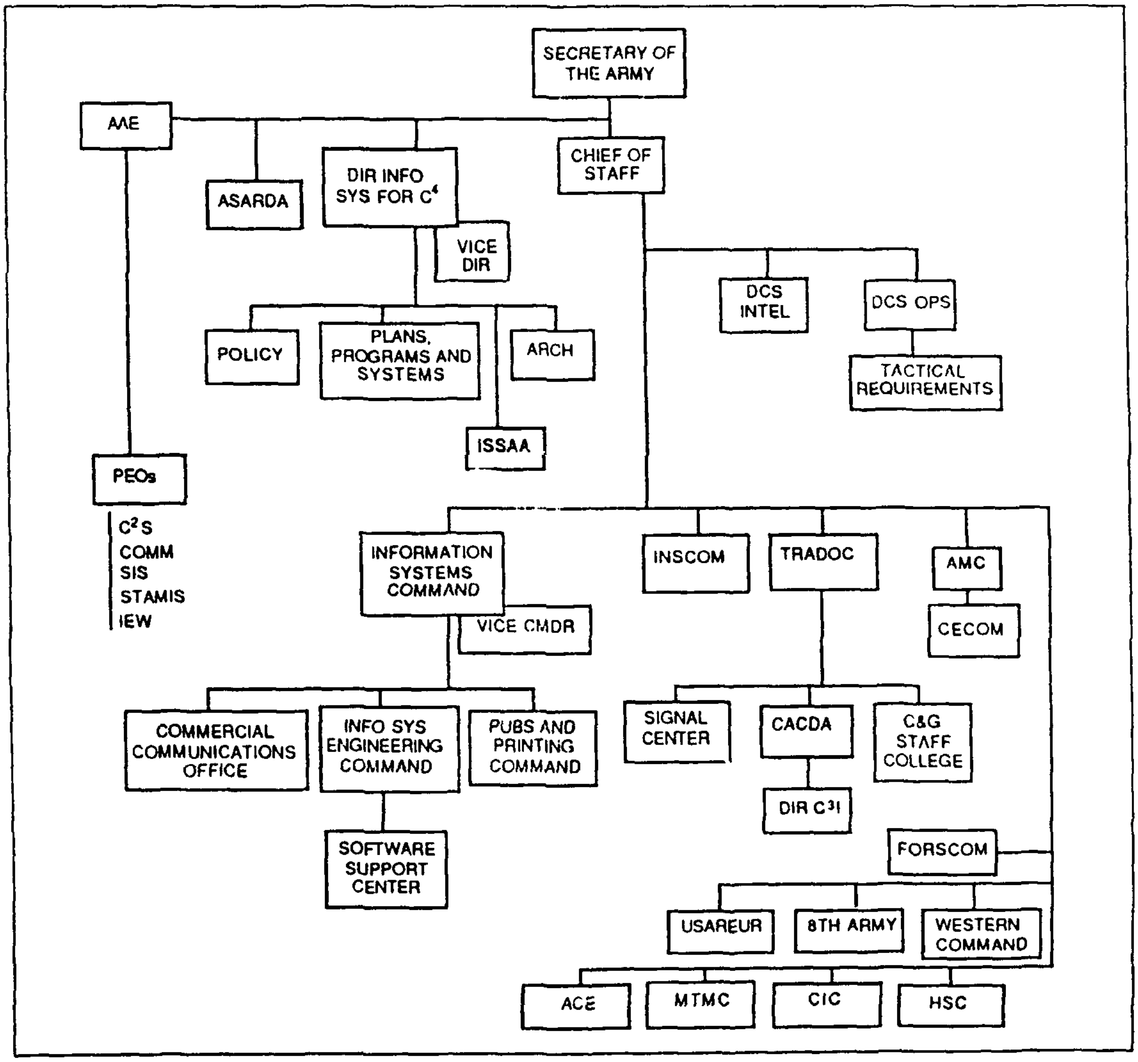
OFFICE OF THE SECRETARY OF DEFENSE AND ORGANIZATION OF THE JOINT CHIEFS OF STAFF



DCA AND JOINT TACTICAL C^3 AGENCY ORGANIZATION

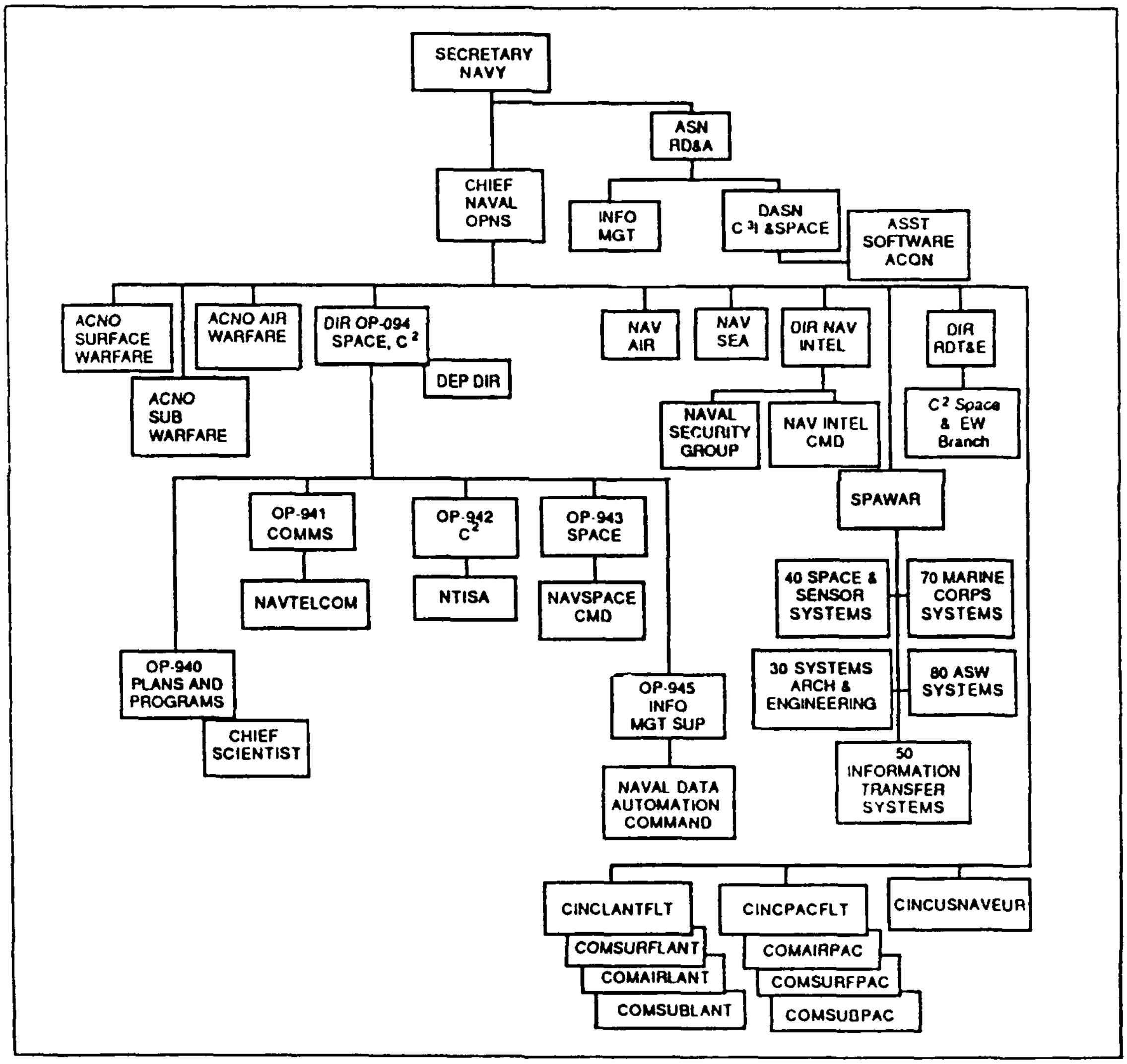


U.S. ARMY



SECRETARY OF THE ARMY
AAE
ASARDA
DIR INFO SYS FOR C^4
CHIEF OF STAFF
VICE DIR
DCS INTEL
DCS OPS
POLICY
PLANS, PROGRAMS AND SYSTEMS
ARCH
TACTICAL REQUIREMENTS
ISSAA
PEOs
C^2S
COMM
SIS
STAMIS
IEW
INFORMATION SYSTEMS COMMAND
VICE CMDR
INSCOM
TRADOC
AMC
CECOM
COMMERCIAL COMMUNICATIONS OFFICE
INFO SYS ENGINEERING COMMAND
PUBS AND PRINTING COMMAND
SIGNAL CENTER
CACDA
C&G STAFF COLLEGE
DIR C^3I
SOFTWARE SUPPORT CENTER
FORSCOM
USAREUR
8TH ARMY
WESTERN COMMAND
ACE
MTMC
CIC
HSC

U.S. NAVY


SECRETARY NAVY
ASN RD&A
CHIEF NAVAL OPNS
INFO MGT
DASN C3I &SPACE
ASST SOFTWARE ACQN
ACNO SURFACE WARFARE
ACNO AIR WARFARE
DIR OP-094 SPACE, C2
DEP DIR
ACNO SUB WARFARE
NAV AIR
NAV SEA
DIR NAV INTEL
DIR RDT&E
NAVAL SECURITY GROUP
NAV INTEL CMD
C2 Space & EW Branch
SPAWAR
OP-941 COMMS
OP-942 C2
OP-943 SPACE
NAVTELCOM
NTISA
NAVSPACE CMD
40 SPACE & SENSOR SYSTEMS
70 MARINE CORPS SYSTEMS
OP-940 PLANS AND PROGRAMS
CHIEF SCIENTIST
OP-945 INFO MGT SUP
30 SYSTEMS ARCH & ENGINEERING
80 ASW SYSTEMS
NAVAL DATA AUTOMATION COMMAND
50 INFORMATION TRANSFER SYSTEMS
CINCLANTFLT
CINCPACFLT
CINCUSNAVEUR
COMSURFLANT
COMAIRLANT
COMSUBLANT
COMAIRPAC
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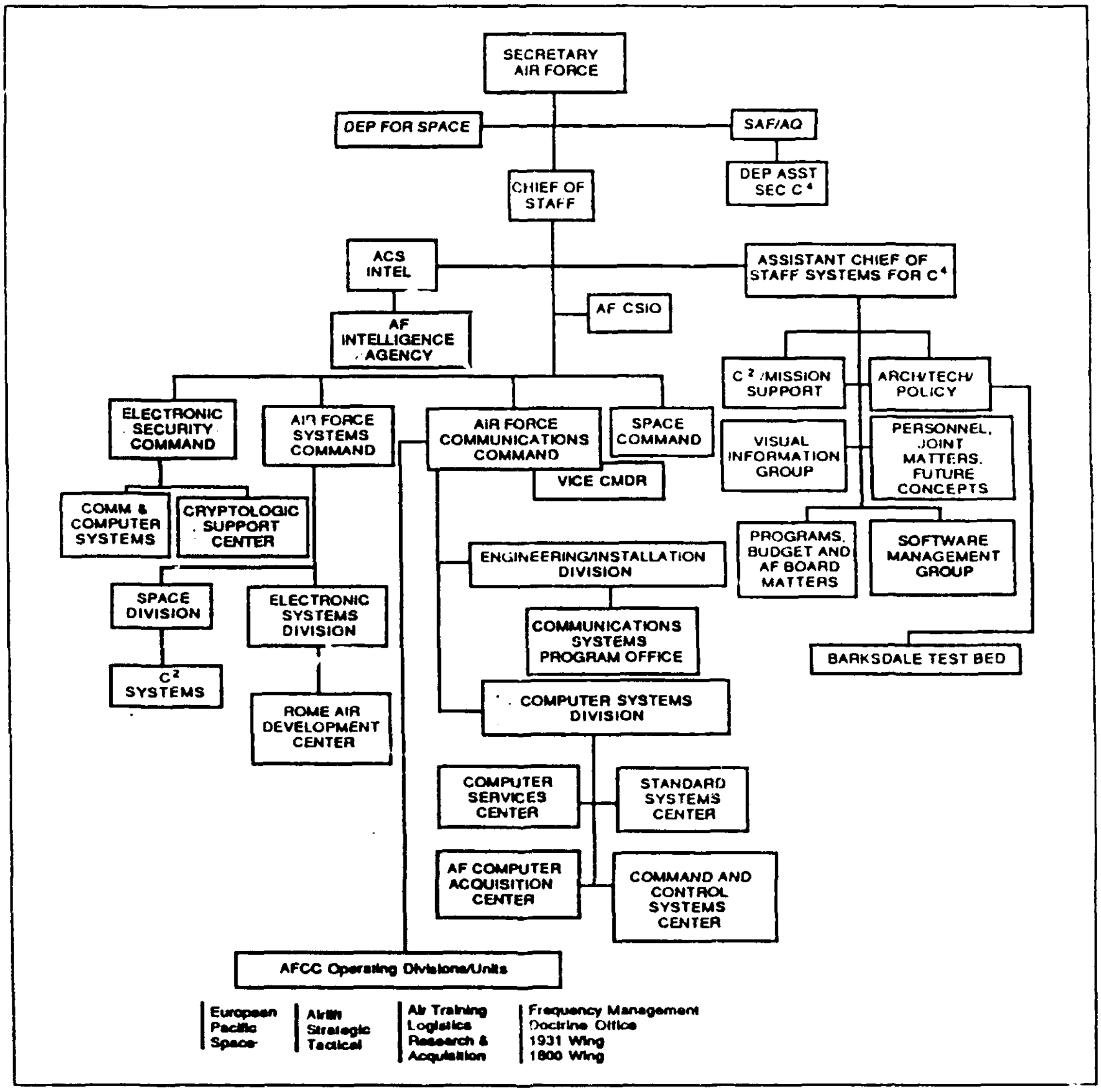
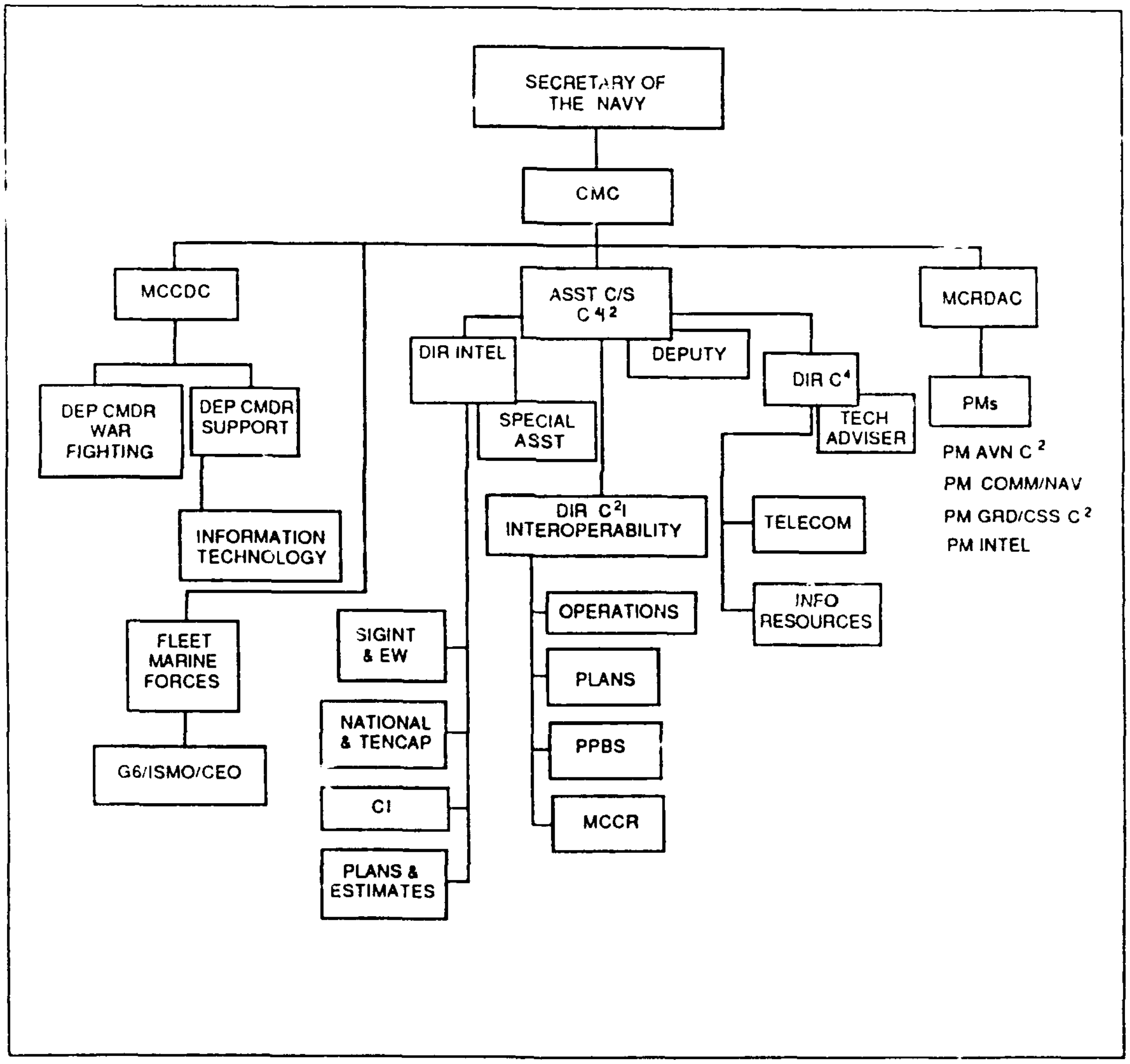
COMSUBPAC

U.S. AIR FORCE


SECRETARY AIR FORCE
DEP FOR SPACE
SAF/AQ
DEP ASST SEC C⁴
CHIEF OF STAFF
ACS INTEL
ASSISTANT CHIEF OF STAFF SYSTEMS FOR C⁴
AF CSIO
AF INTELLIGENCE AGENCY
C²/MISSION SUPPORT
ARCH/TECH/ POLICY
ELECTRONIC SECURITY COMMAND
AIR FORCE SYSTEMS COMMAND
AIR FORCE COMMUNICATIONS COMMAND
SPACE COMMAND
VISUAL INFORMATION GROUP
PERSONNEL, JOINT MATTERS, FUTURE CONCEPTS
VICE CMDR
COMM & COMPUTER SYSTEMS
CRYPTOLOGIC SUPPORT CENTER
PROGRAMS, BUDGET AND AF BOARD MATTERS
SOFTWARE MANAGEMENT GROUP
ENGINEERING/INSTALLATION DIVISION
SPACE DIVISION
ELECTRONIC SYSTEMS DIVISION
COMMUNICATIONS SYSTEMS PROGRAM OFFICE
BARKSDALE TEST BED
C² SYSTEMS
ROME AIR DEVELOPMENT CENTER
COMPUTER SYSTEMS DIVISION
COMPUTER SERVICES CENTER
STANDARD SYSTEMS CENTER
AF COMPUTER ACQUISITION CENTER
COMMAND AND CONTROL SYSTEMS CENTER
AFCC Operating Divisions/Units
European
Pacific
Space
Airlift
Strategic
Tactical
Air Training
Logistics
Research & Acquisition
Frequency Management
Doctrine Office
1931 Wing
1800 Wing

U.S MARINE CORPS



APPENDIX B

ABBREVIATIONS, ACRONYMS AND DIRECTIVES

AAE	Army acquisition Executive
ACE	Army Corps of Engineers
ACNO	Assistant Chief of Naval Operations
ACQN	Acquisition
ACS	Assistant Chief of Staff
ADP	Automated Data processing
AFCC	Air Force Communications Command
AFCSIO	Air Force Communications–Computers Integration Office
ARCH	Architecture
ASARDA	Assistant Secretary Army Research Development Acquisition
ASD	Assistant Secretary of Defense
ASN R,E&S	Assistant Secretary of the Navy, Research, Engineering and Support
C & G Staff College	Command and General Staff College
C^2	Command and Control
C^2I	Command, Control and Intelligence
C^3	Command, Control and Communications
C^3CM	C^3 Countermeasures
C^3I	Command, Control, Communications and Intelligence
C^4	Command, Control, Communications and Computers
C^4I^2	Command, control, communications, Computers, Intelligence and Interoperability
C6/ISMO/CEO	Communications/Information Systems Management Office/Communications–Electronics Office
CACDA	Combined Arms Combat Development Activity
CI	Counter Intelligence
CIC	Counter Intelligence Command
CINC	Commander in Chief
CINCLANTFLT	Commander in Chief, Atlantic Fleet
CINCPACFLT	Commander in Chief, Pacific Fleet
CINCUSNAVEUR	Commander in Chief, U.S. Navy Europe
CMC	Commandant, Marine Corps
CNO	Chief of Naval Operations
CNOD	Counter Narcotics Operations Division (OJCS)
COMAIRLANT	Commander, Air Atlantic
COMAIRPAC	Commander, Air Pacific
COMSUBLANT	Commander, Submarine Atlantic
COMSUBPAC	Commander, Submarines Pacific

COMSURFLANT	Commander, Surface Atlantic
COMSURFAC	Commander, Surface Pacific
DASD	Deputy Assistant Secretary of Defense
DASN C^3I and Space	Deputy Assistant Secretary of the Navy for Command, Control, Communications and Intelligence and Space
DCA	Defense Communications Agency
DCS	Defense Communications System
DMS	Defense Message System
DOD	Department of Defense
DSCS	Defense Satellite Communications System
EW	Electronic Warfare
HSC	Health Service Command
IEW	Intelligence and Electronic Warfare
INSCOM	Intelligence and Security Command
ISDN	Integrated Services Digital Network
ISSAA	Information Systems Selection and Acquisition Agency
J–3	Operations Directorate
J–4	Logistics Directorate
J–5	Strategic Plans & Policy Directorate
J–6	Command, Control, Communications Systems Directorate
J–7	Operational Plans & Interoperability Directorate
J–8	Force Structure, Resource and Assessment Division
JCS	Joint Chiefs of Staff
JDSSC	Joint Data Systems Support center (DCA)
JITC	Joint Interoperability Test Center (DCA–JTC^3A)
JITF	Joint Interface Test Force (DCA–JTC^3A)
JTC^3A	Joint Tactical C^3 Agency
JVIDS	Joint Visually Integrated Display System (OJCS)
MCCDC	Marine Corps Combat Development Command
MCCR	Mission Critical Computer Resources
MCEB	Military Communications–Electronics Board
MIS	Management Information Systems
MTMC	Military Traffic Management Command (Army)
NAVTELCOM	Naval Telecommunications Command
NCA	National Command Authority
NCCS	Navy Command and Control System
NDI	Nondevelopment Item(s)
NMCS	National Military Command and Control System
NORAD	North American Aerospace Defense Command
NTDS	Navy Tactical Data System
NTISA	Naval Tactical Interoperability Support Agency
OPNAV	Office of the Chief of Naval Operations
OSD	Office of the Secretary of Defense
PACAF	Pacific Air Forces
PEO	Program Executive Officer
PM	Program Manager
PM COMM/NAV	Program Manager, Commuications/Navigation
PM GRD/CSS C^2	Program Manager, Ground/Combat Service Support Command and Control

PM INTEL	Program Manager, Intelligence
POM	Program Objective memorandum
PPBS	Planning, Programming and Budgeting System
RADC	Rome Air Development Center
SAF/AAD	Directorate of Information Management (AF) (Office Symbol)
SAF/AK	Deputy Assistant Secretary of Air Force for C^4 Systems (Office symbol)
SAF/AQ	Assistant Secretary of Air Force—Acquisition (Office Symbol)
SECNAV	Secretary of the Navy
SIGINT	Signal Intelligence
SIS	Strategic Information Systems
SPAWAR	Space and Naval Warfare
STAMIS	Standard Army Management Information Systems
TENCAP	Tactical Exploitation of National Capabilities
TRADOC	Training and Doctrine Command
WAM	WWMCCS Automation Modernization (DCA)
WG	Working Group
WHCA	White House Communications agency
WIN	WWMCCS Intercomputer network
WIS	WWMCCS Information System
WWMCCS	World Wide Military Command and Control System

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Naval Postgraduate School
Monterey, CA 93943

11. Captain Seong Seung Park 1
Dobong 2 dong, # 625–113
Dobong–Ku, Seoul
Zip Code 132–062
Republic of korea

12. Captain Il Joong Kim 1
Dongbu–dong, Hanyang Apartment # 503
Andong City, Kyung–Book
Zip Code 760–050
Republic of Korea

13. Captain Jae Doo Jung 1
SMC 1504
Naval Postgraduate School
Monterey, CA 93943

14. Major Won Tae Jin 1
SMC 1737
Naval Postgraduate School
Monterey, CA 93943

15. Captain Byung Kook Choi 1
SMC 1587
Naval Postgraduate School
Monterey, CA 93943

16. Captain Sook Hwan Kim 1
SMC 2318
Naval Postgraduate School
Monterey, CA 93943

17. Captain Jeong Hyun Park 1
SMC 1818
Naval Postgraduate School
Monterey, CA 93943

18. Lieutenant Man Soo Choi 1
Keukdong Apartment #4–403
Kyesan–Dong, Inchon
Zip Code 403–050
Republic of Korea

19. Lieutenant Heu Byung Yoon 1
SMC 2137
Naval Postgraduate School
Monterey, CA 93943

20. Major Jae Yong Yim 1
Bong Yoang Dong 1339
(Young Mi Super 2nd Floor)
Chung Joo, Chung Book
Zip Code 360–300
Republic of Korea

21. Major Sung Hoon Go 1
SuYoo 4 Dong, 286–38
Dobong–Gu, Seoul
Zip Code 132–074
Republic of Korea

22. Captain In Sub Shin 7
Kayagok–Myun, Sannori 518
Nonsan–Gun, Chung Nam
Zip Code 320–840
Republic of Korea